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EFFECT OF GROUND PROXIMITY ON THE LONGITUDINAL AERODYNAMIC CHARACTERISTICS OF AN ASPECT-RATIO-1 WING WITH AND WITHOUT WING-TIP BLOWING

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16. Abstract

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The results indicate that the model is stable with height and pitch at positive angles of attack and that the lift-drag ratio is improved at small ground heights with some blowing at the wing tips.

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SUMMARY

An investigation has been conducted to determine the effect of ground proximity on the aerodynamic characteristics of an aspect-ratio-1 wing with and without wing-tip blowing. This investigation was conducted in the Langley towing tank no. 1 (no longer a Langley facility) with the model towed over the water to eliminate the effects of walls and of wind-tunnel ground-board boundary layers.

Increasing the tip-jet blowing coefficient at a constant angle of attack increased the lift and drag in the positive direction and the pitching moment in the negative direction. The lift-curve slope increased with increasing tip-jet blowing coefficient and decreasing ground height. At a positive angle of attack, the model was stable both with height and pitch. The lift-drag ratio was improved for the 90° and 135° tip jets at small ground heights with some blowing at the wing tips.

INTRODUCTION

The need for a high-speed ground transportation system has promoted considerable interest in ground-effect machines. One possible vehicle, the peripheral jet in ground proximity, has shown large thrust augmentation in hover, but the inlet-momentum drag from the air required to produce the jet is relatively high at forward speeds. This high drag leads to small lift-drag ratios and therefore poor cruise performance. (See refs. 1 and 2.) The lift-drag ratio may be improved by transferring all or part of the lift from jet thrust and base lift to lift from a shape similar to an airplane wing.

An investigation of the aerodynamic characteristics of a wing in close ground proximity has been conducted in the Langley towing tank no. 1 (no longer a Langley facility) to obtain some data for use in predicting the performance of an airfoil-shaped ground-effect machine at forward speeds. Since ground-effect machines generally have aspect ratios of 1 or less, a wing having an aspect ratio of 1 was used in this investigation. The investigation was performed with the model moving over the water in the tank rather than in a wind tunnel in order to eliminate the effects of wind-tunnel walls and of the boundary layer on a wind-tunnel ground board. Lift, drag, and pitching-moment data were obtained on an 11-percent-thick airfoil with and without full-chord tip-jet blowing at tip-jet deflection angles of 0°, 90°, and 135° from the wing plane. (See fig. 1.) A related investigation using the same airfoil with and without end plates is represented in reference 3.

SYMBOLS

The units used for the physical quantities defined in this paper are given in the International System of Units (SI) and parenthetically in the U.S. Customary Units. Conversion factors for the SI system are presented in reference 4.

The longitudinal aerodynamic data are presented in the stability-axis system with the pitching moment resolved about the quarter chord on the lower surface of the wing. (See fig. 1(b).)

b	wing span, 1.22 m (4.00 ft)
c	wing chord, 1.22 m (4.00 ft)
C_D	drag coefficient, $D/q_{\infty}S$
C_L	lift coefficient, $L/q_{\infty}S$
ΔC_L	increment in lift coefficient due to interference, $C_L - \left[\left(C_L\right)_{\text{power off}} + C_{\mu} \sin \delta_j \cos \alpha\right]$
C_m	pitching-moment coefficient about 0.25c, $M_Y/q_{\infty}Sc$
C_{μ}	tip-jet blowing coefficient, $\dfrac{\text{Static jet thrust}}{q_{\infty}S}$
D	drag, N (lbf)
h	height from water surface to lower surface of airfoil at 0.25c, m (ft)

L	lift, N (lbf)
M_Y	pitching moment about 0.25c, N-m (ft-lbf)
q_∞	free-stream dynamic pressure, $\frac{1}{2}\rho_\infty V_\infty^2$, N/m^2 (lbf/ft^2)
S	wing area, 1.48 m^2 (16.00 ft^2)
V_∞	free-stream velocity, m/sec (ft/sec)
α	angle of attack, deg
δ_j	tip-jet deflection angle (see fig. 1), deg
ρ_∞	free-stream density, kg/m^3 (slugs/ft^3)

MODEL AND APPARATUS

The model tested was an aspect-ratio-1 wing having a square planform with a 1.22-m (4.00-ft) chord and span. The airfoil section used was an 11-percent-thick Glenn Martin 21 section (ref. 5) with the lower surface modified to have a flat bottom between the 30-percent-chord station and the trailing edge. (See fig. 1.) Full-chord jets were mounted on the lower corner of the wing tips in such a way that the direction of the jet could be set at angles of 0°, 90°, and 135° from the wing plane. Each tip jet consisted of a 2.24-cm (0.88-in.) inside-diameter closed pipe which served as a plenum chamber and two side plates converging to a 0.079-cm-wide (0.031-in.) slot which formed the jet exit. The tip-jet plenum chamber was supplied compressed air through a flexible air line from a pressure vessel mounted on the towing carriage. (There was no external air inlet on the model.)

The investigation was conducted in the Langley towing tank no. 1 (no longer a Langley facility). Details of the tank and some of the apparatus used during the test can be found in reference 6. By towing the model over the water, the effects of wind-tunnel walls and of the boundary layer on a wind-tunnel ground board were eliminated. The model was supported by a strain-gage balance attached to a post on the towing carriage as shown in figure 2. The height of the model, measured from the lower surface of the wing at the 25-percent-chord station, could be varied by raising or lowering either the model or the water level in the tank. The thrust of each tip jet was measured statically by the strain-gage balance and was calibrated as a function of the static pressure in each tip-jet plenum chamber. This calibration was used to determine the tip-jet blowing coefficient during the tests.

TESTS

Data were obtained at heights from 0.06 to 1.63 wing spans through a range in tip-jet blowing coefficient at several angles of attack from -4° to 15°. At the smaller heights, the angle of attack was restricted by the clearance requirement to keep the leading and trailing edges of the model above the water. All data were obtained at a forward speed of 22 m/sec (72 ft/sec) which corresponded to a Reynolds number based on wing chord of 1.84×10^{6}.

PRESENTATION OF RESULTS

It should be noted that the drag did not include any inlet-momentum drag, and the angle of attack was measured from the flat part of the lower surface of the airfoil. The results are presented in the stability-axis system as follows:

	Figure
Photographs showing typical powered tests	3
Variation of the longitudinal aerodynamic characteristics of the model with tip-jet blowing coefficient	4 to 6
Effect of tip-jet blowing coefficient on the longitudinal aerodynamic characteristics	7 to 9
Variation of the longitudinal aerodynamic characteristics of the model with ground proximity	10
Effect of ground proximity on the longitudinal aerodynamic characteristics	11
Effect of tip-jet blowing coefficient on the interference in lift	12

DISCUSSION

Some typical photographs of the model at small ground heights (fig. 3) demonstrate that the blowing of the tip jets does not significantly change the level of the water except near the jet itself. Therefore, no corrections have been made to the height for variations due to the jet exhaust.

Variation of Longitudinal Aerodynamic Characteristics With Tip-Jet Blowing

The results showing the variation of the longitudinal aerodynamic characteristics with tip-jet blowing coefficient for the three tip-jet deflection angles are presented in figures 4 to 6. The tip-jet blowing coefficient could not be precisely set from angle to angle because of difficulties in setting the tip-jet plenum-chamber pressure. To facilitate the analysis, the data have been faired, cross plotted, and extrapolated in some cases to present the longitudinal data for various ground heights and jet-deflection angles at constant values of C_μ. (See figs. 7 to 9.)

All configurations tested showed negative pitching moments. At positive angles of attack, increasing the tip-jet blowing coefficient increased the lift and drag in the positive direction and the pitching moment in the negative direction. At negative angles of attack, the results varied.

The results showing the effect of tip-jet blowing coefficient on the variation of longitudinal aerodynamic characteristics with angle of attack are presented in figures 7 to 9. Generally, increasing the tip-jet blowing coefficient increased the lift-curve slope and changed the angle of zero lift. The maximum lift-drag ratio increased with tip-jet blowing coefficient for the 90° and 135° jets and decreased for the 0° jets. The change in longitudinal static stability with blowing coefficient was small, but the static stability increased with lift coefficient.

The additional lift at an angle of attack arose from direct as well as induced effects of the tip jets. The direct effects of the jet thrust partially accounted for the changes in lift, drag, and pitching moment. The component of jet thrust in the lift direction is $C_\mu \sin \delta_j \cos \alpha$ and in the drag direction is $C_\mu \sin \delta_j \sin \alpha$. If the resultant force from the jet thrust acts at the 0.50c, the pitching moment due to jet thrust is $(0.25 - 0.50)C_\mu \sin \delta_j$. If there are no large interference effects, increasing the tip-jet blowing coefficient at a positive angle of attack should increase the lift and drag and make the pitching moment more negative. The induced effects came from the interference of the jet flow with the flow from the lower surface to the upper surface, like an end plate, so that the wing tips could carry greater lift.

For the 0° tip jets, the tip-jet blowing coefficient did not have much effect on the maximum lift-drag ratio. For the 90° and 135° tip jets, the maximum lift-drag ratio increased with tip-jet blowing except for the 90° tip jets at the smallest ground height ($h/b = 0.06$). The lift coefficient for maximum lift-drag ratios ranged from 0.2 to 0.4 for the 90° tip jets and from 0.3 to 0.7 for the 135° jets. Problems in operating at very small ground heights may preclude taking advantage of the high lift-drag ratios obtained for the 135° jets in close ground proximity ($h/b = 0.06$).

Variation of the Longitudinal Aerodynamic Characteristics With Ground Proximity

The variation of the longitudinal aerodynamic characteristics with ground proximity is presented in figure 10 at an angle of attack of 2°. The effects of ground proximity were small at heights above 0.2 wing spans, but increased rapidly at heights below 0.2 wing spans. At an angle of attack of 2°, the lift and drag became more positive and the pitching moment more negative with decreasing ground height. The power-on ground effects are greater than the power-off ground effects because of the "cushion" or "fountain" effect occurring when the air from the tip jet is turned under the wing.

A ground-effect machine has height stability if, when it is disturbed from its equilibrium height, the change in lift tends to restore the equilibrium height; that is, for height stability, the slope of the lift-height curve dC_L/dh must be negative. All three tip-jet deflection angles are stable with height at an angle of attack of 2°. The height stability increased with decreasing ground height.

The effect of ground proximity on the longitudinal aerodynamic characteristics at a tip-jet blowing coefficient of 0.3 is presented in figure 11. Decreasing the height increased the lift-curve slope and changed the maximum lift-drag ratio. The maximum lift-drag ratio increased with decreasing ground height for the 0° and 135° tip jets, but it varied for the 90° tip jets.

Effect of Tip-Jet Blowing Coefficient on the Interference Lift

The forces on the model arise from the effects of the free stream, from the thrust of the jet, and from the mutual interference of the jet, ground, and free stream. At a constant angle of attack, the interference lift, represented by ΔC_L, was computed by subtracting the lift at that angle of attack without wing-tip blowing and the lift due to jet thrust $\left(C_{\mu} \sin \delta_j \cos \alpha\right)$ from the lift with the tip jets blowing:

$$\Delta C_L = C_L - \left[\left(C_L\right)_{\text{power off}} + C_{\mu} \sin \delta_j \cos \alpha\right]$$

Beneficial interference would be represented by a positive ΔC_L. The results of these computations are presented in figure 12 for the three tip-jet deflection angles at several heights.

Generally, the interference lift became more beneficial with increasing angle of attack. When the interference lift is beneficial at an angle of attack, increasing the tip-jet blowing coefficient increased the beneficial interference.

For the 0° tip jets both in and out of ground effect, the interference was beneficial at positive angles of attack above 2° and detrimental at negative angles of attack. For the

90° tip jets out of ground effect, the tip-jet blowing was detrimental; in ground effect at positive angles of attack the interference was beneficial. For the 135° tip jets out of ground effect, blowing was detrimental to the interference; in ground effect, the interference was always beneficial. The interference in lift ranges from about -0.3 to 0.55, depending upon the tip jet deflection angle, height, blowing coefficient, and angle of attack. This interference can be a significant part of the total lift coefficient and should not be neglected when predicting the performance of ground-effect machines.

CONCLUSIONS

The results of the investigation on the effect of tip-jet blowing coefficient on the aerodynamic characteristics of an aspect-ratio-1 wing led to the following conclusions:

1. Increasing the tip-jet blowing coefficient at a constant positive angle of attack causes the lift and drag to increase in the positive direction and the pitching moment in the negative direction. Also, the lift-curve slope increases with increasing tip-jet blowing coefficient and decreasing ground height.

2. At positive angles of attack, the model was stable both with pitch and with height.

3. The lift-drag ratio was improved for the 90° and the 135° tip jets at small ground heights with some blowing at the wing tips.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., April 18, 1974.

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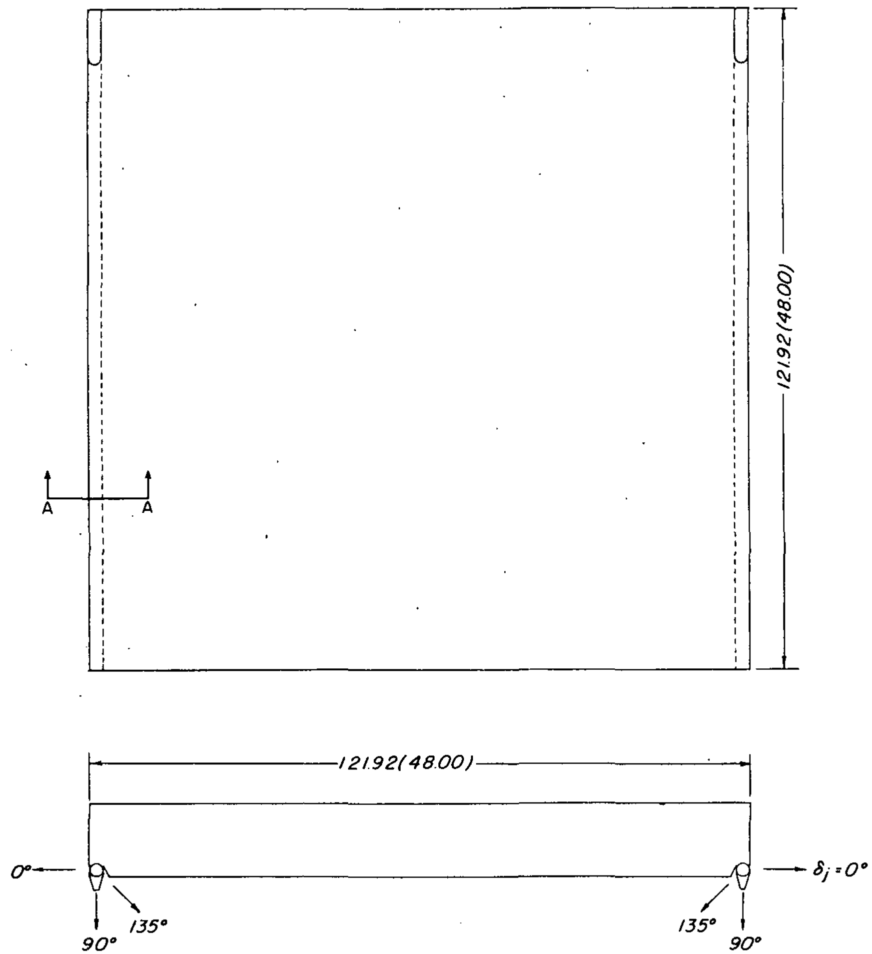
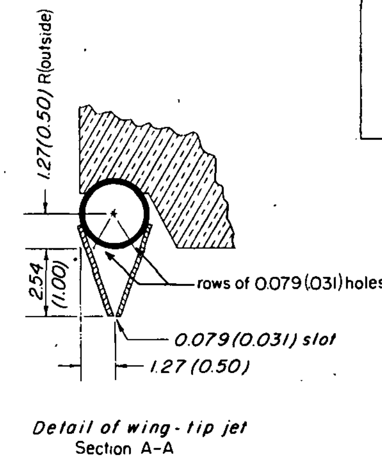
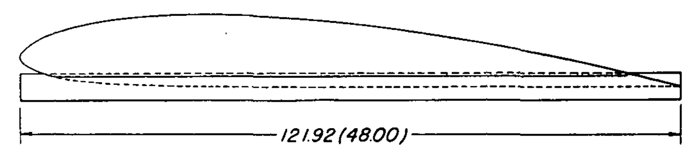


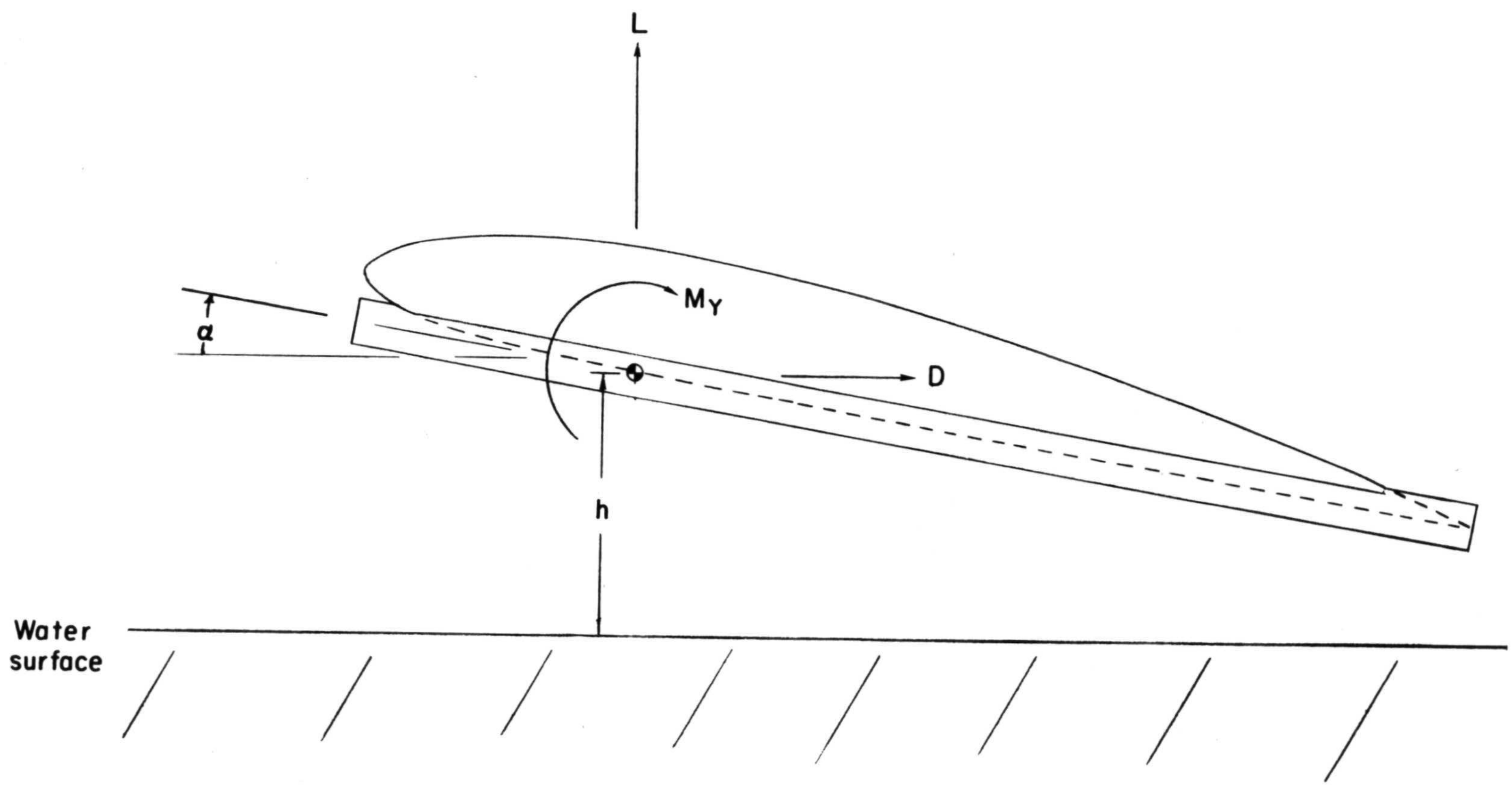




Station, percent chord	Airfoil ordinates, percent chord	
	Upper	Lower
0	4.43	4.43
1.25	6.10	3.02
2.5	6.90	2.40
5	7.99	1.66
7.5	8.82	1.18
10	9.46	.86
15	10.36	.38
20	10.84	.14
30	11.06	0
40	10.56	0
50	9.60	0
60	8.32	0
70	6.68	0
80	4.72	0
90	2.50	0
95	1.28	0
100	0	0

(a) Model and airfoil ordinates.

Figure 1.- Three-view drawing, airfoil ordinates, forces, and moments of model. Dimensions are given in centimeters and parenthetically in inches unless otherwise noted.



(b) Positive direction of forces and moments.

Figure 1.- Concluded.

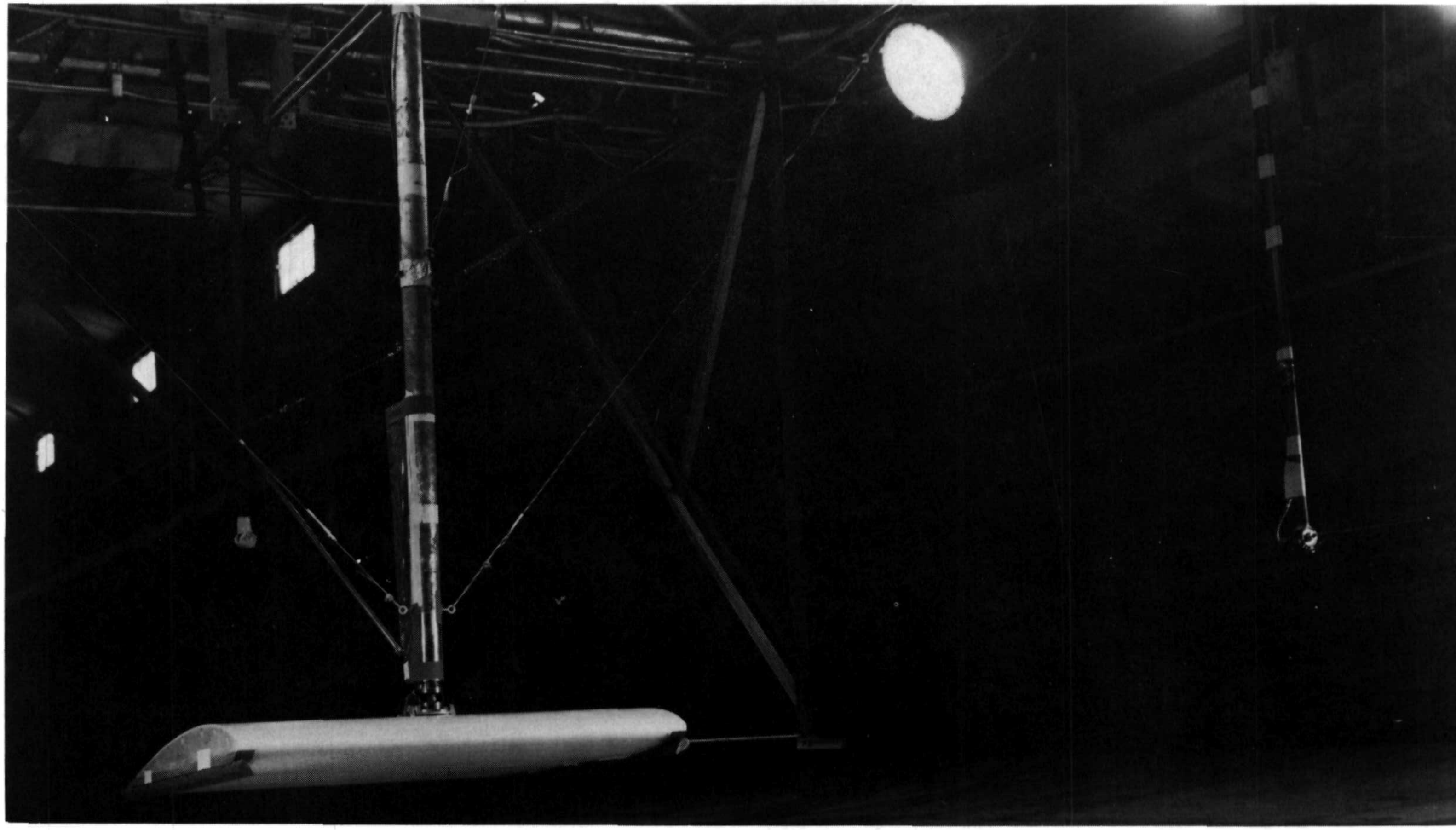


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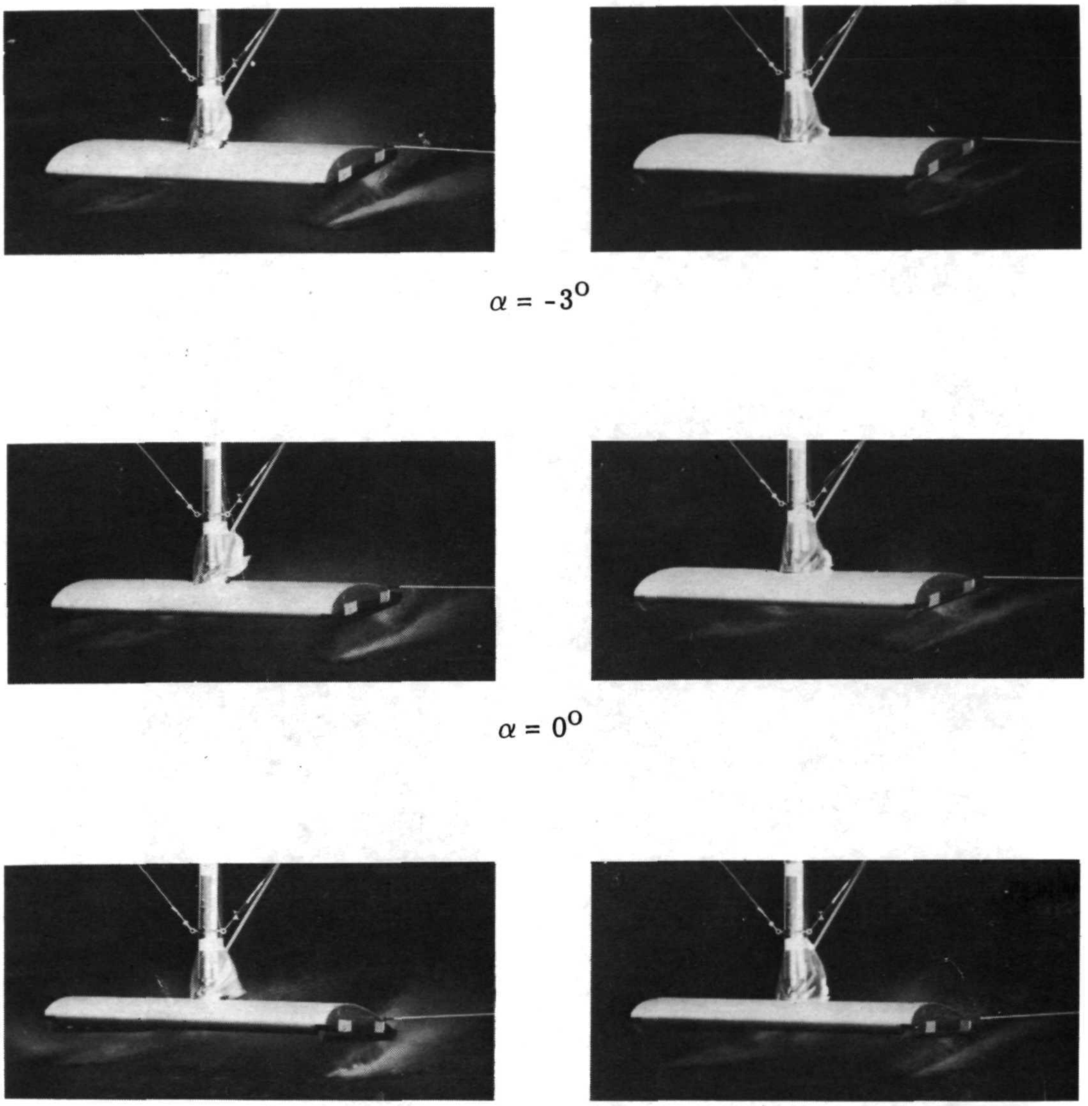
Figure 2.- Photograph of model and setup on towing carriage in Langley towing tank no. 1.



$\delta_j = 90^\circ$ $\delta_j = 135^\circ$

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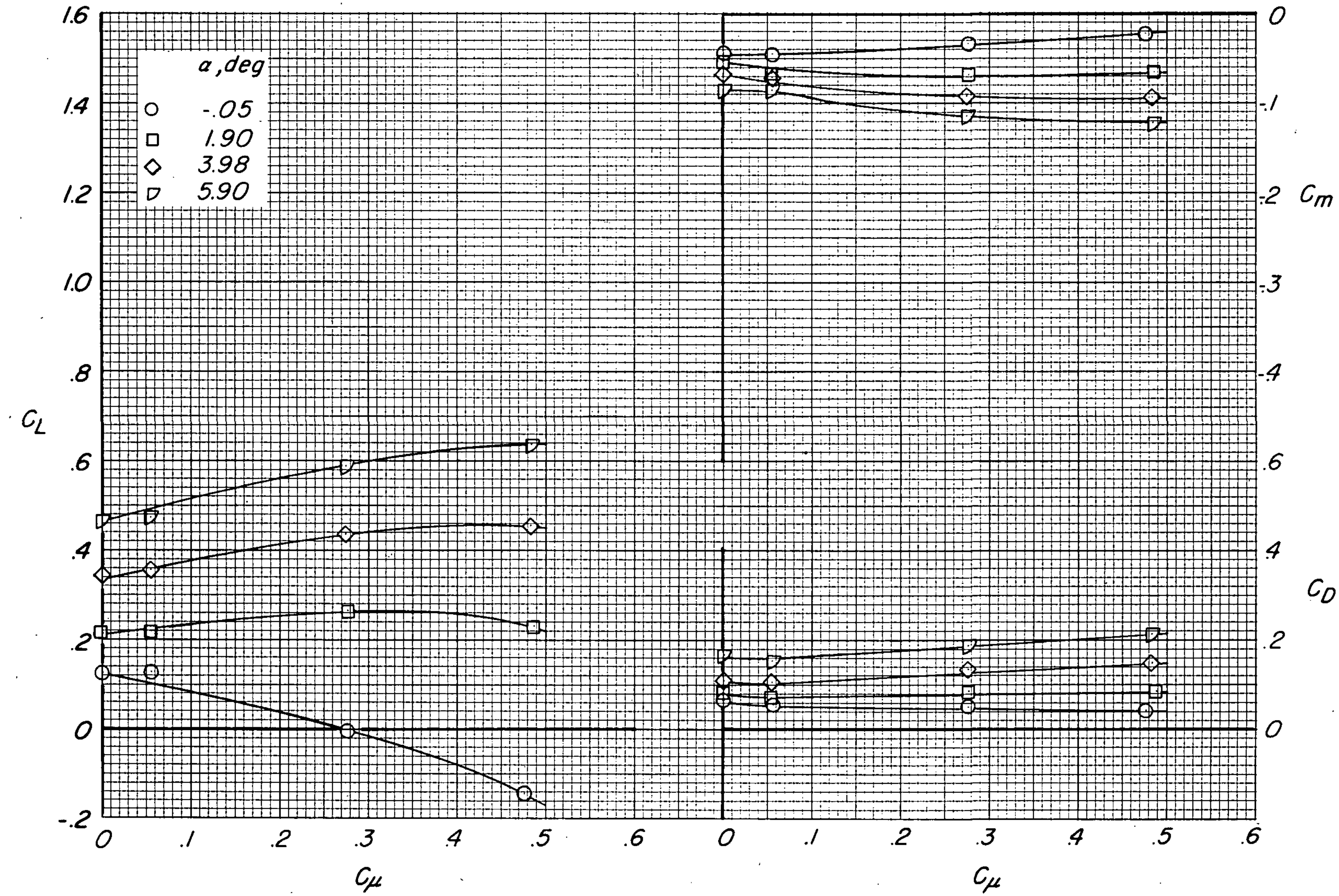
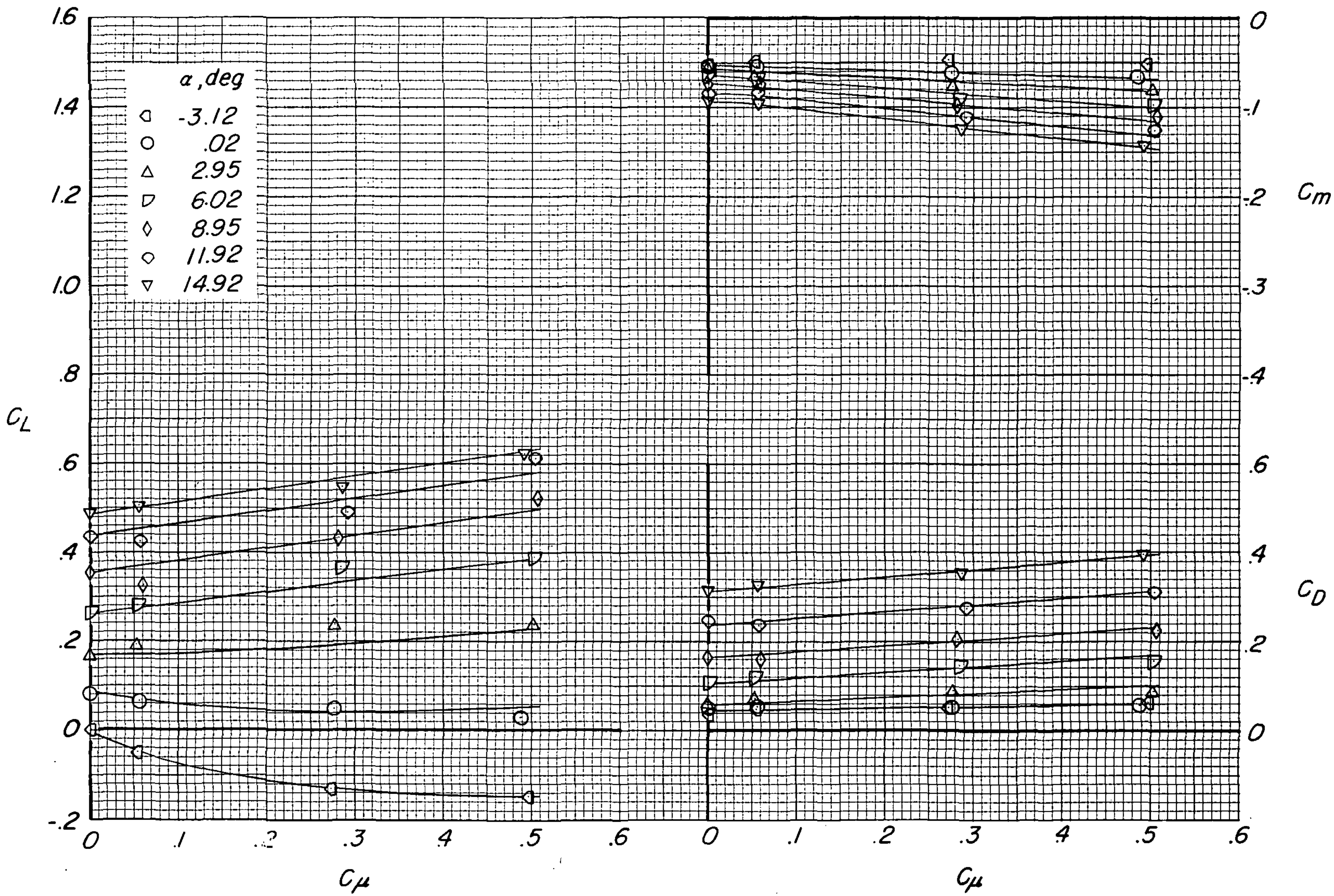
Figure 3.- Typical photographs of model during investigation at $h/b \approx 0.14$.



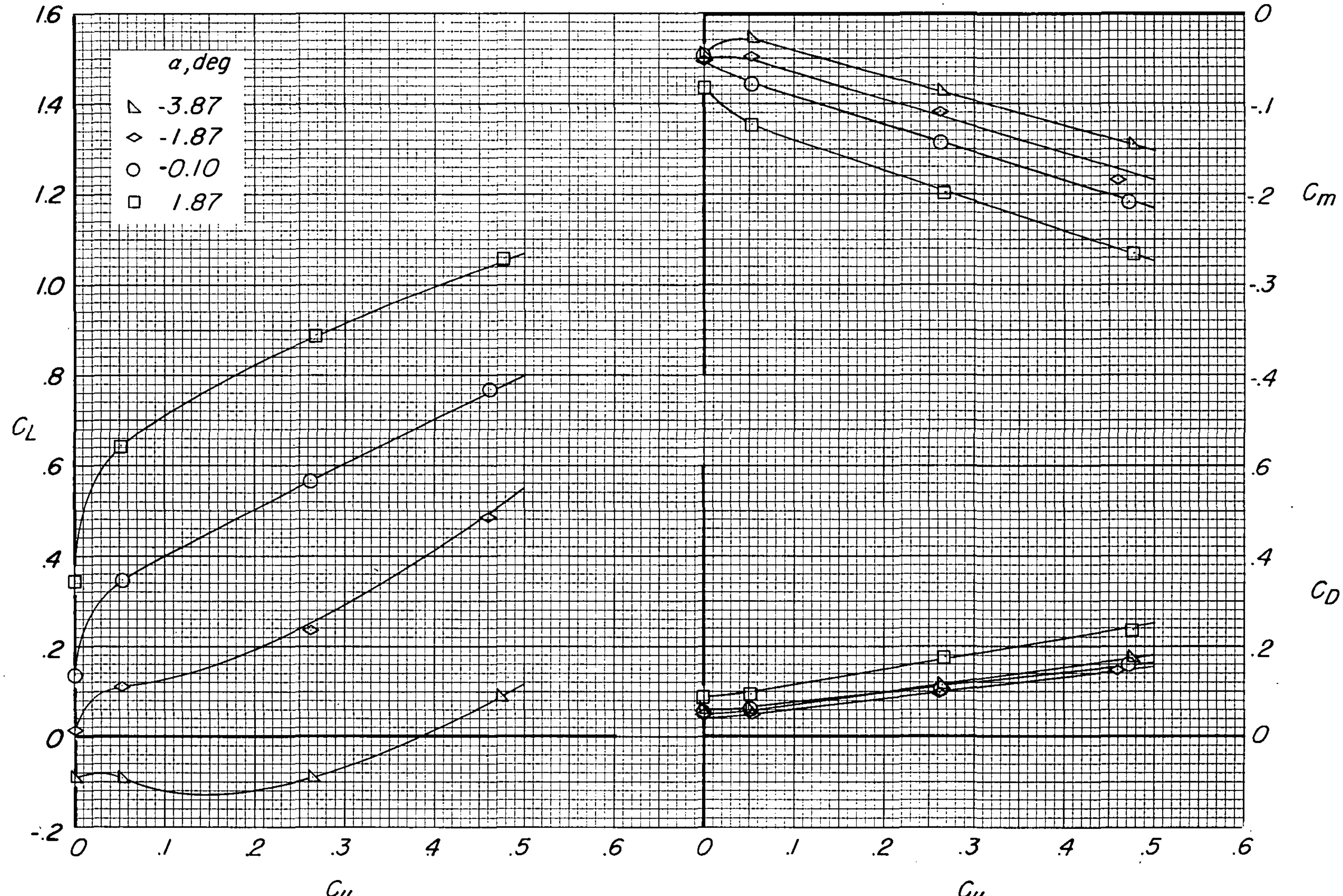
(a) h/b = 0.112.

Figure 4.- Variation of longitudinal aerodynamic characteristics of the model with C_μ. $\delta_j = 0^o$.



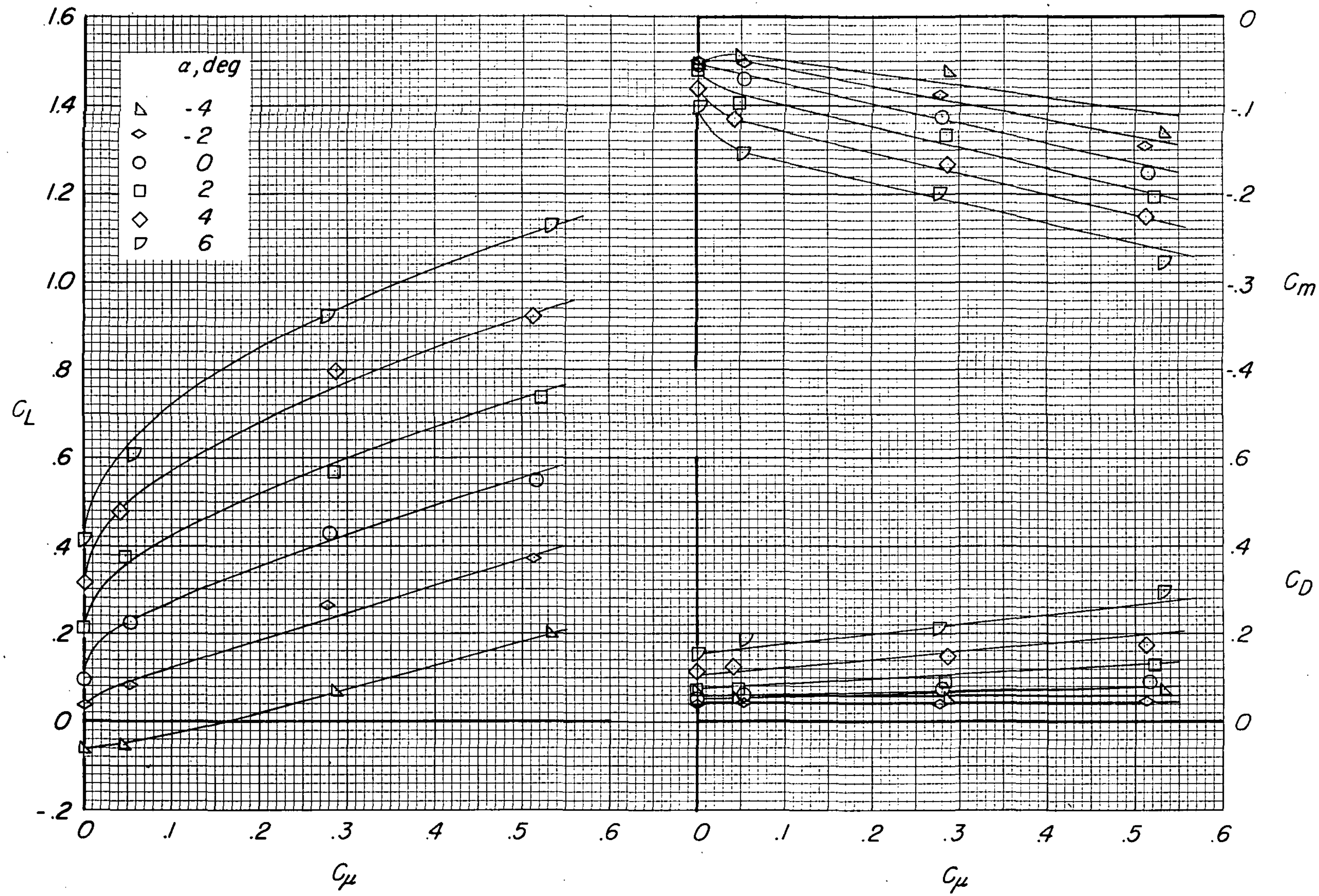
(b) h/b = 1.418.

Figure 4.- Concluded.



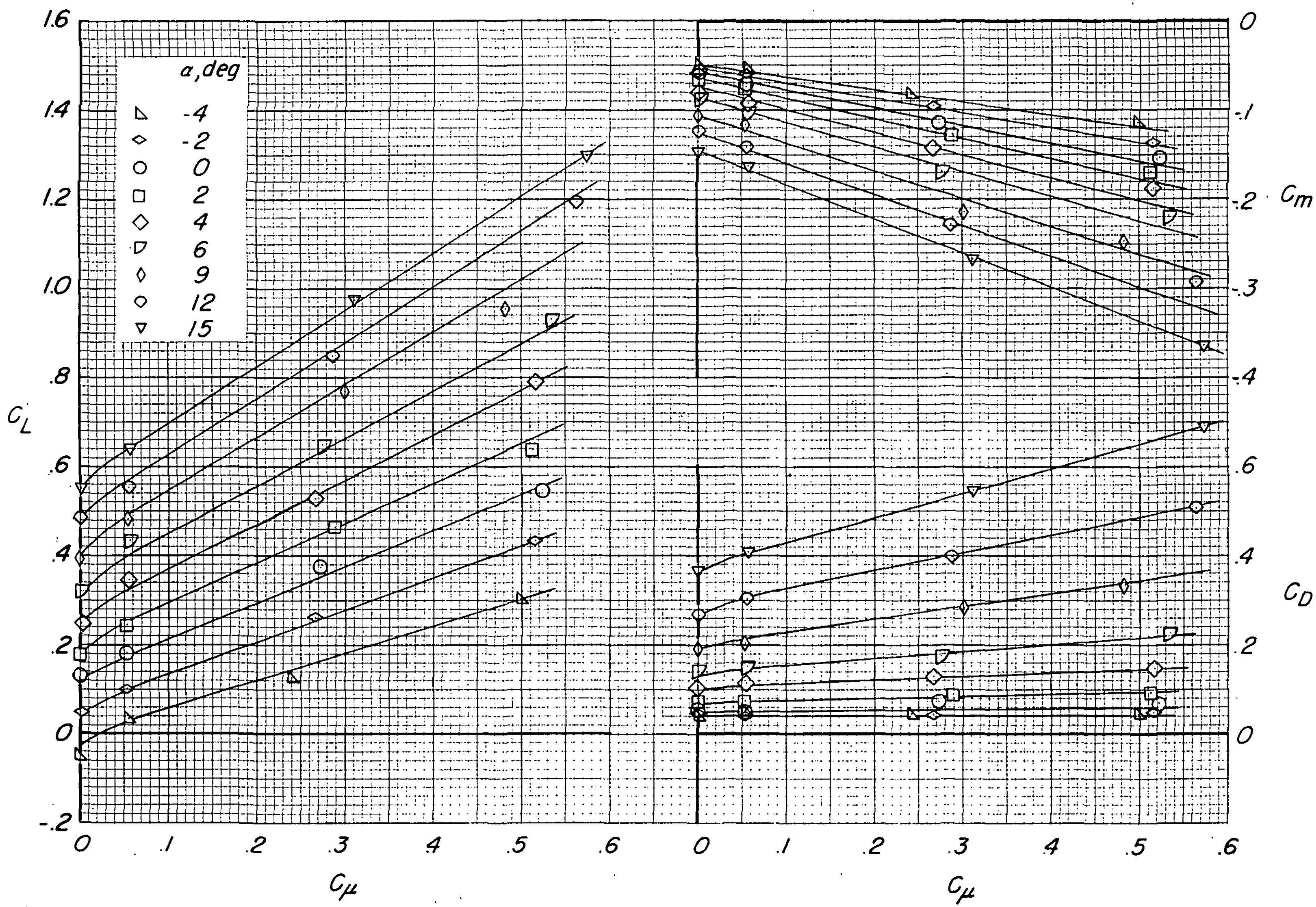
(a) h/b = 0.068.

Figure 5.- Variation of longitudinal aerodynamic characteristics of the model with C_μ. $\delta_j = 90^o$.



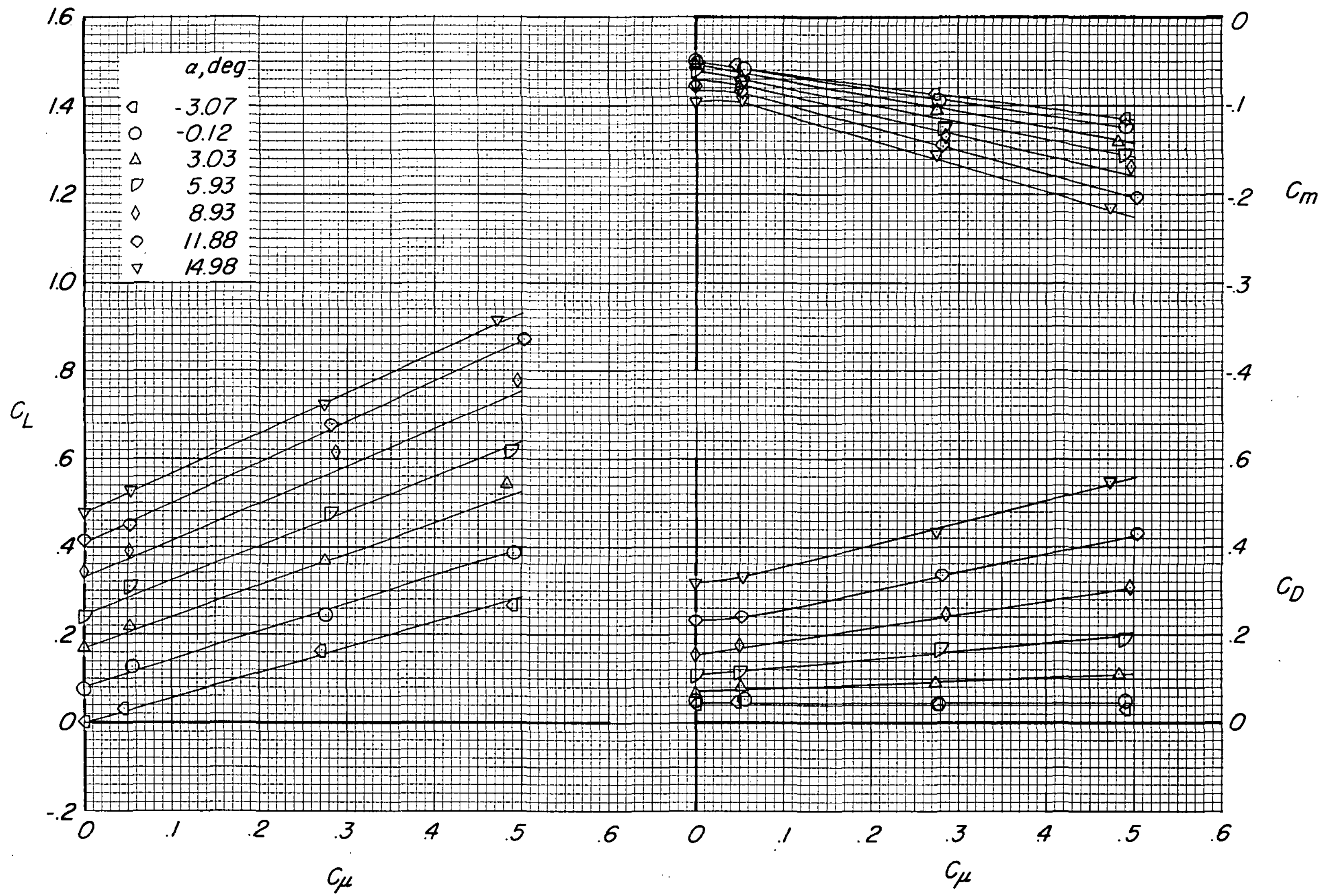
(b) h/b = 0.112.

Figure 5.- Continued.



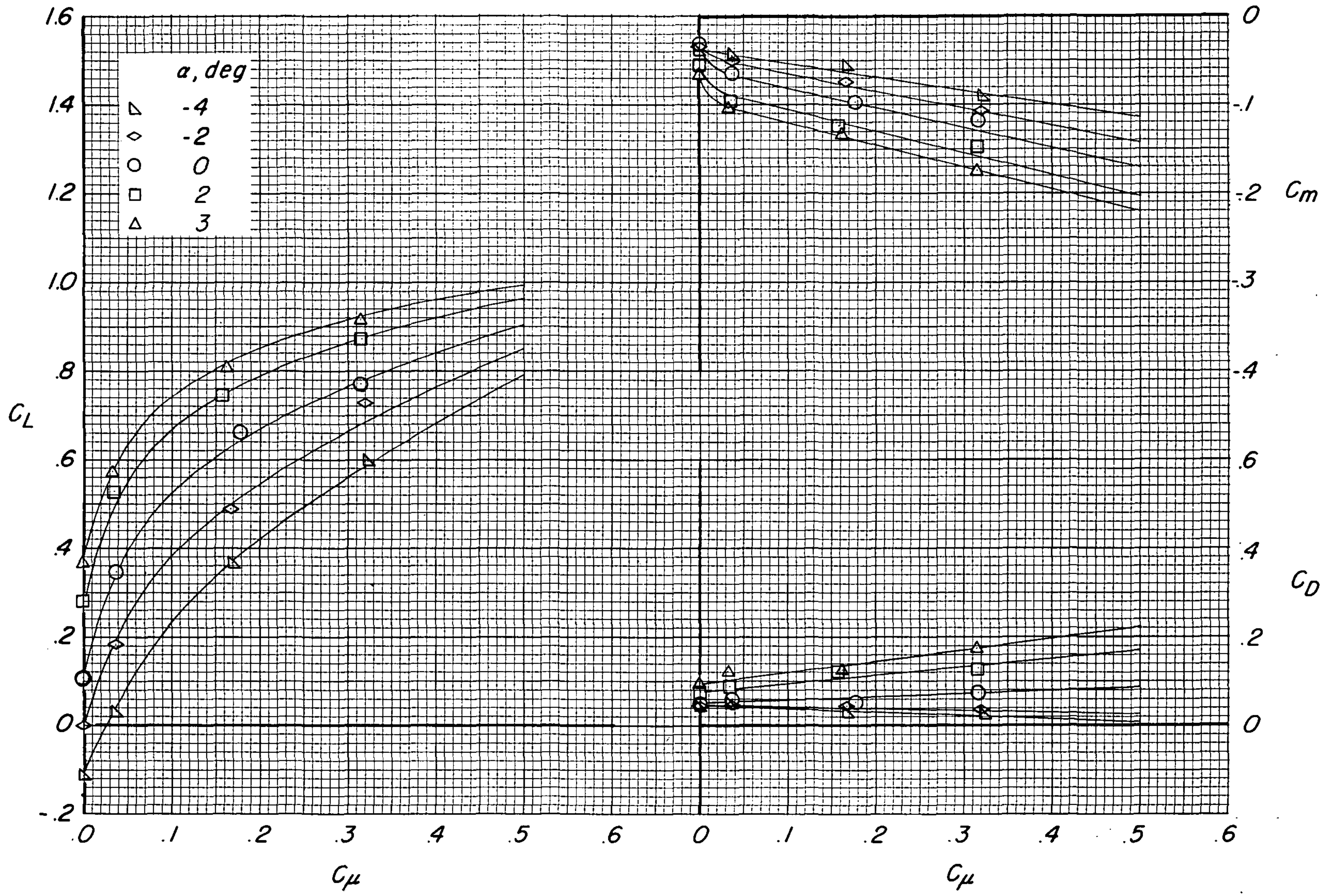
(c) h/b = 0.255.

Figure 5.- Continued.



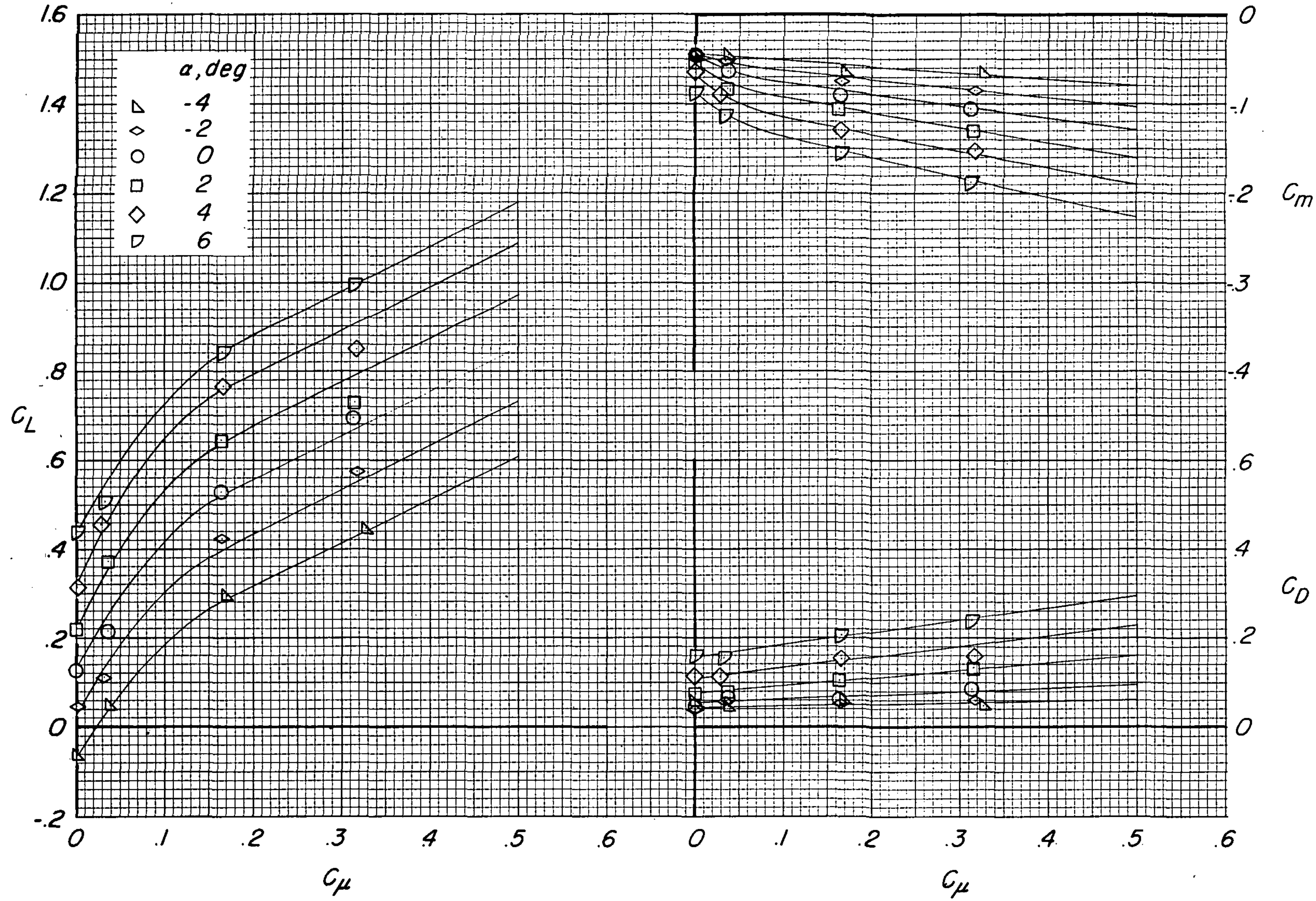
(d) h/b = 1.418.

Figure 5.- Concluded.



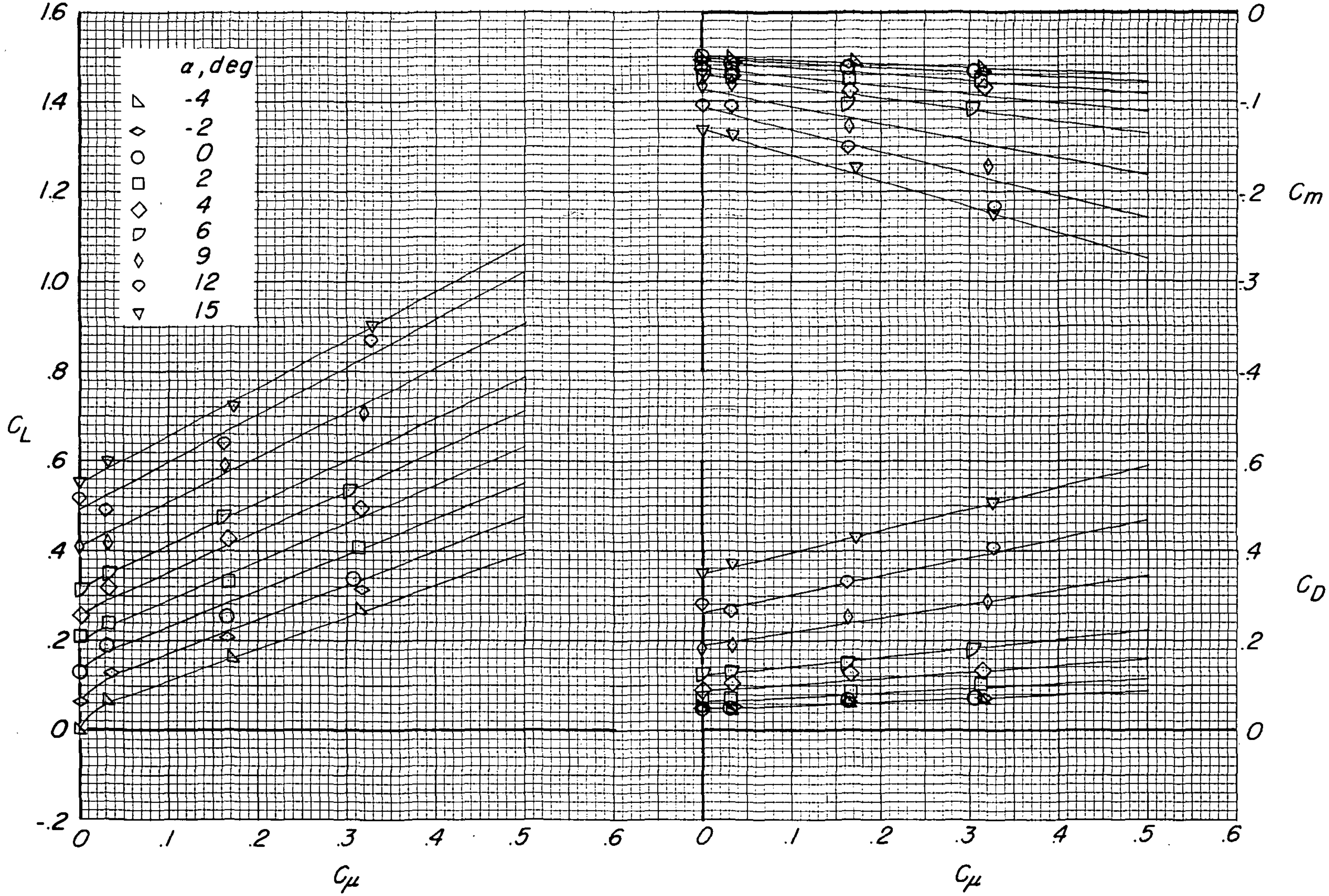
(a) h/b = 0.063.

Figure 6.- Variation of longitudinal aerodynamic characteristics of the model with C_μ. $\delta_j = 135^\circ$.



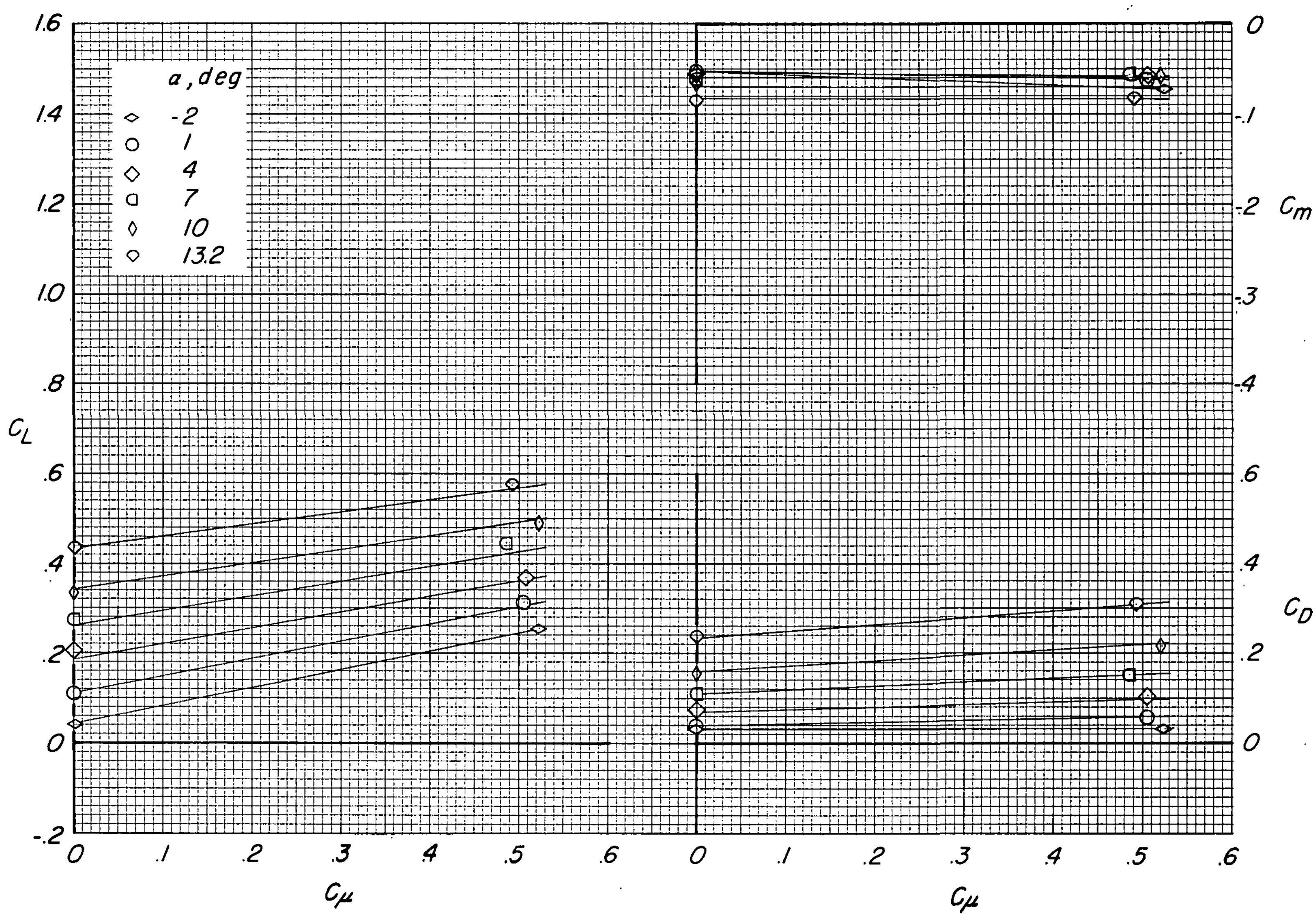
(b) h/b = 0.113.

Figure 6.- Continued.



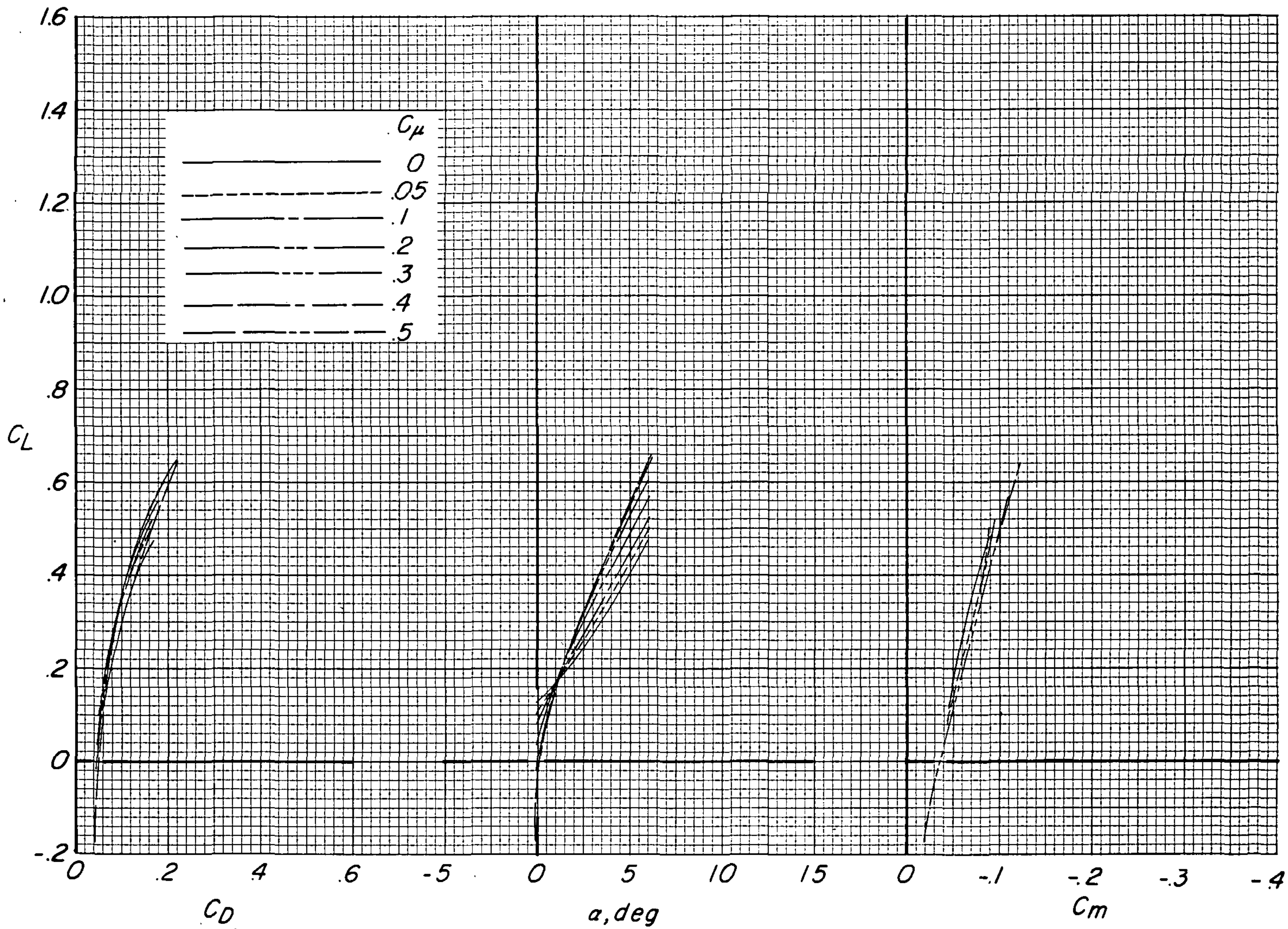
(c) h/b = 0.270.

Figure 6.- Continued.



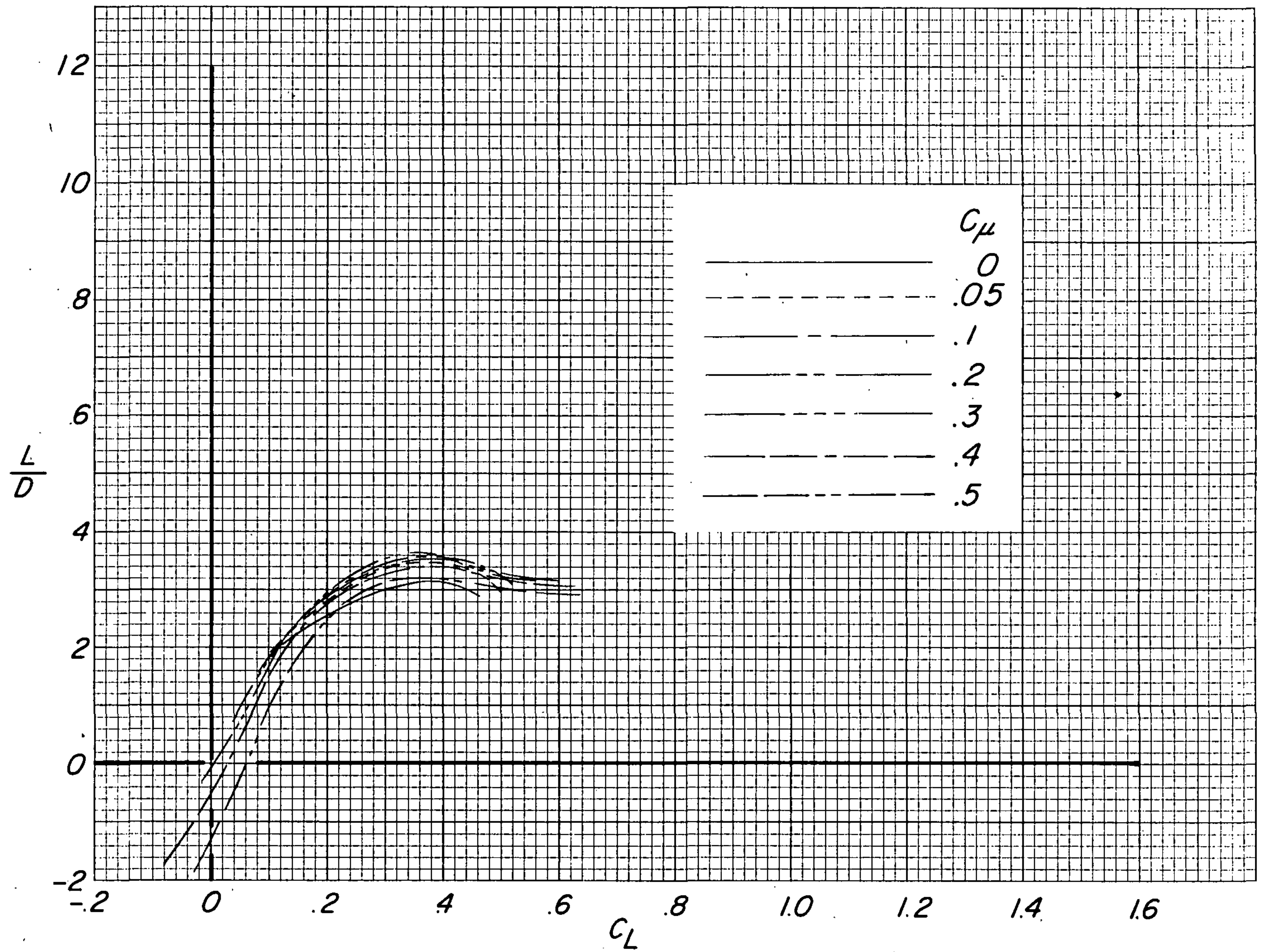
(d) h/b = 1.630.

Figure 6.- Concluded.



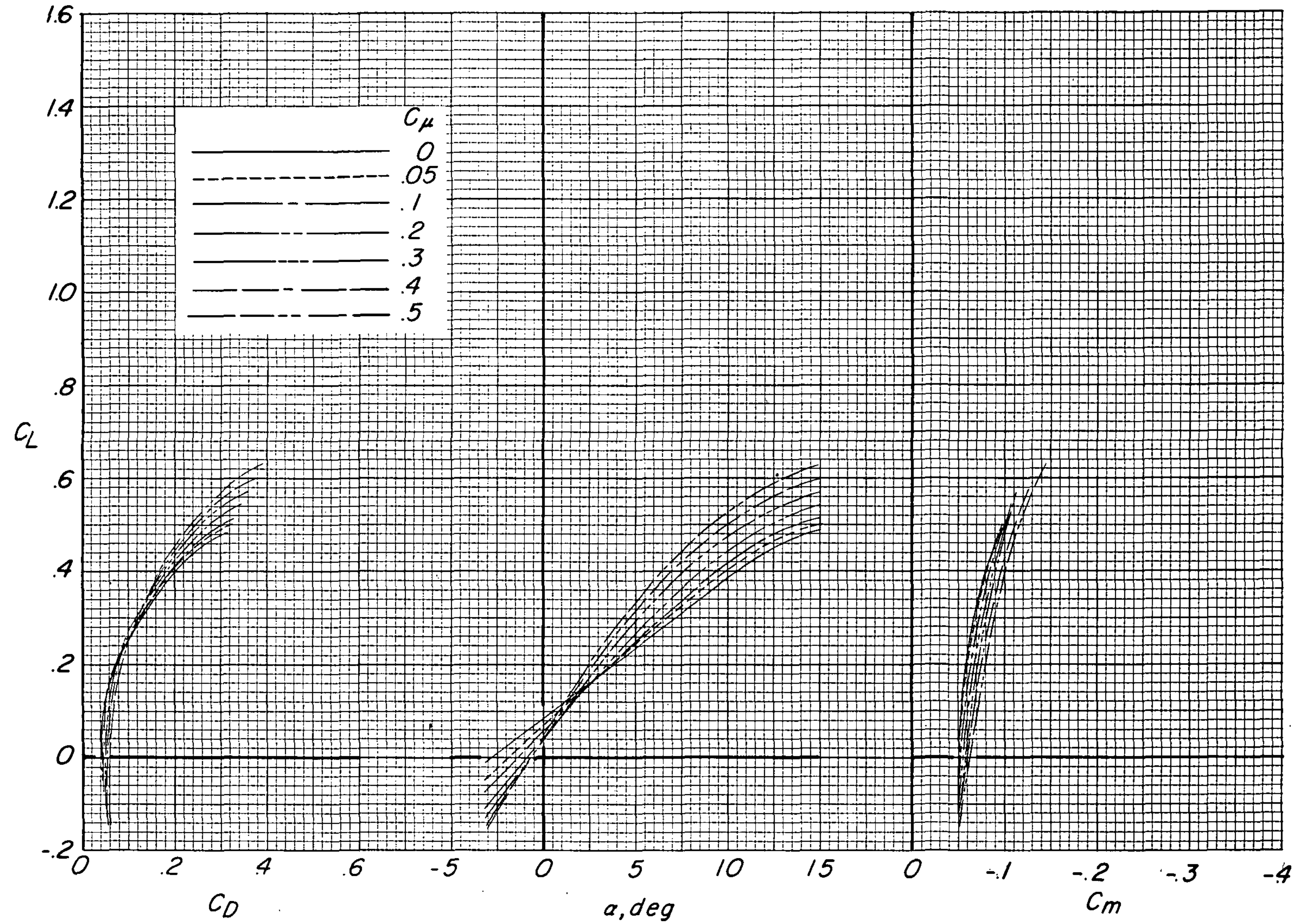
(a) $h/b = 0.112$.

Figure 7.- Effect of C_μ on the longitudinal aerodynamic characteristics of the model with wing-tip jets deflected 0°.



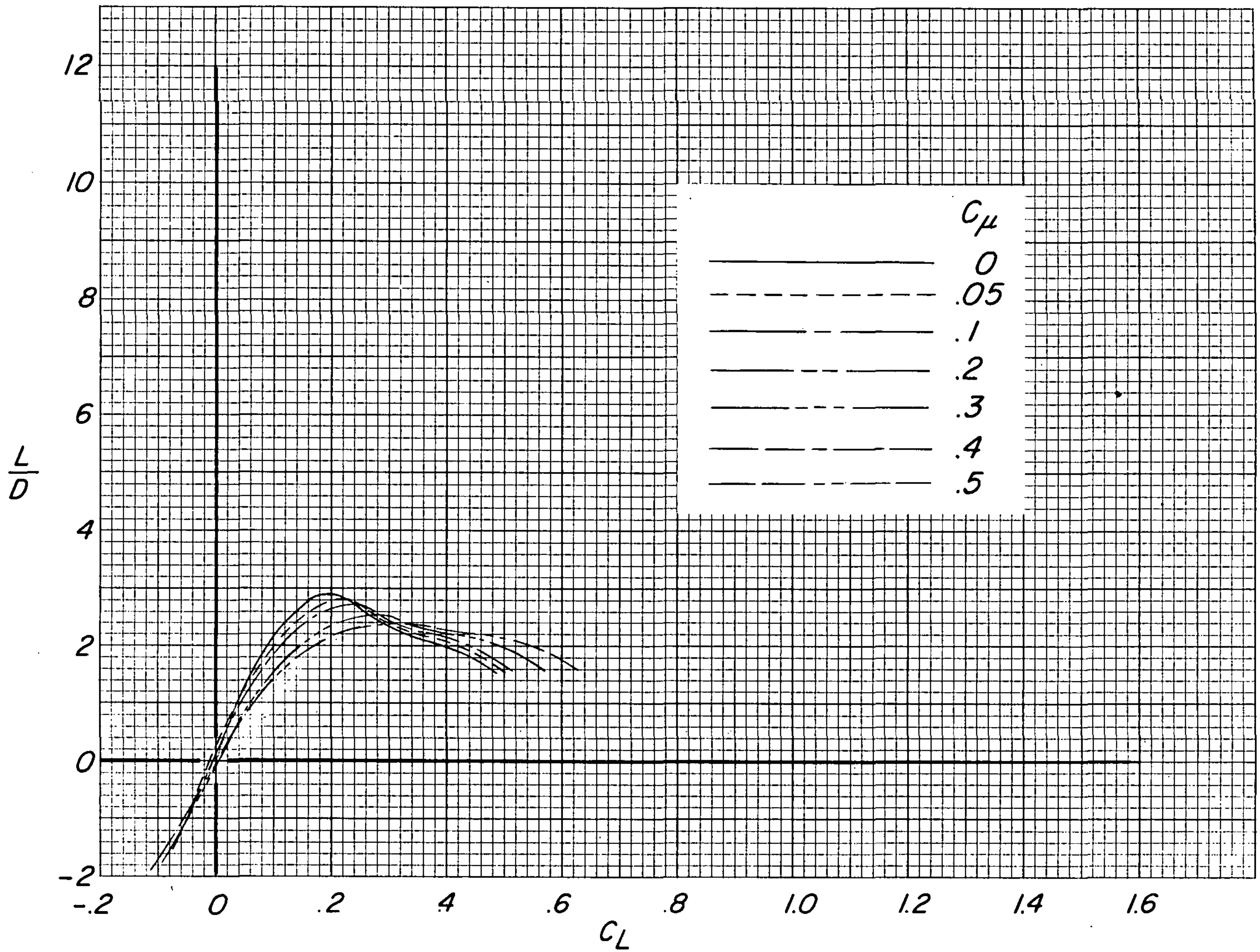
(a) Concluded.

Figure 7.- Continued.



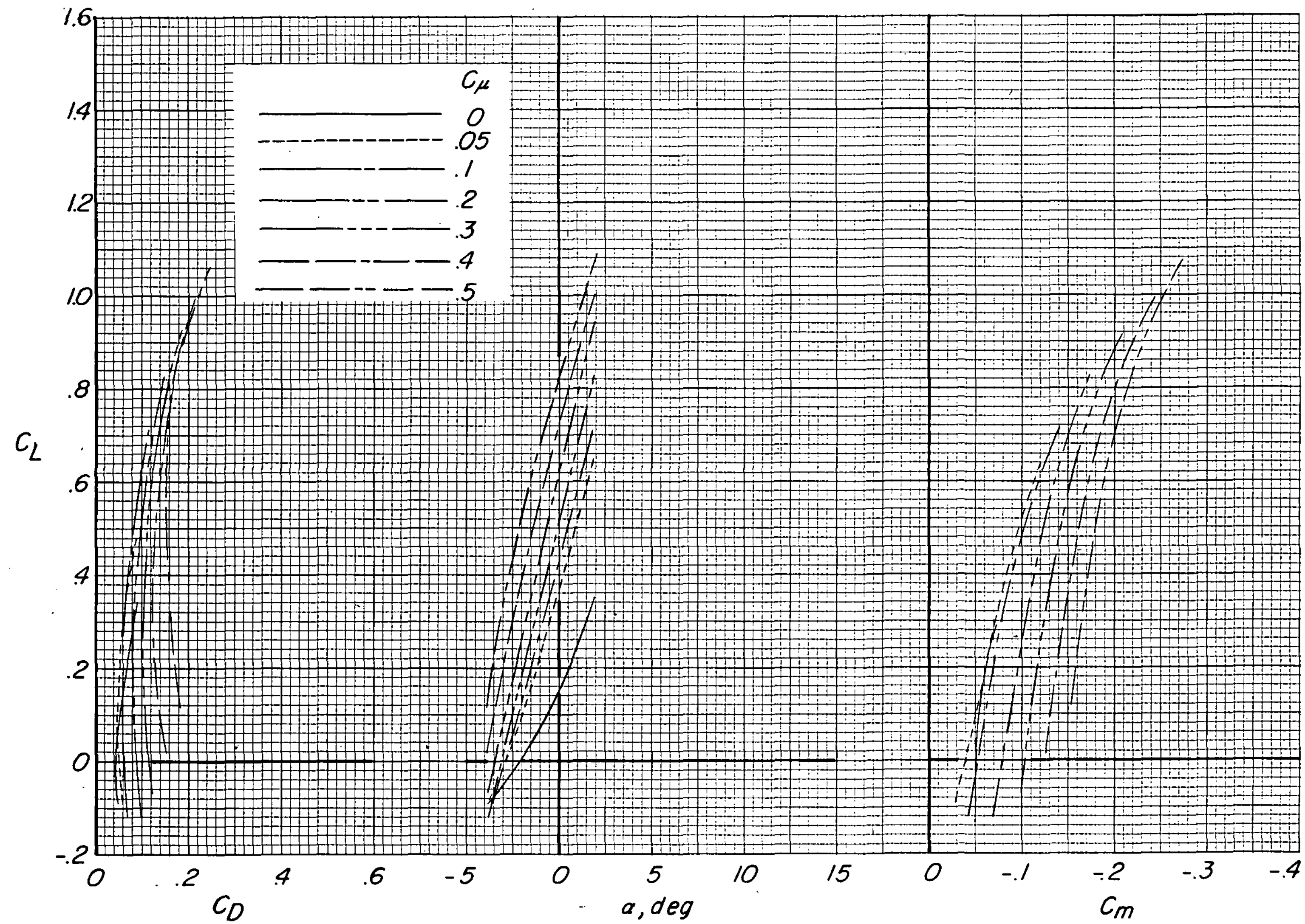
(b) h/b = 1.418.

Figure 7.- Continued.



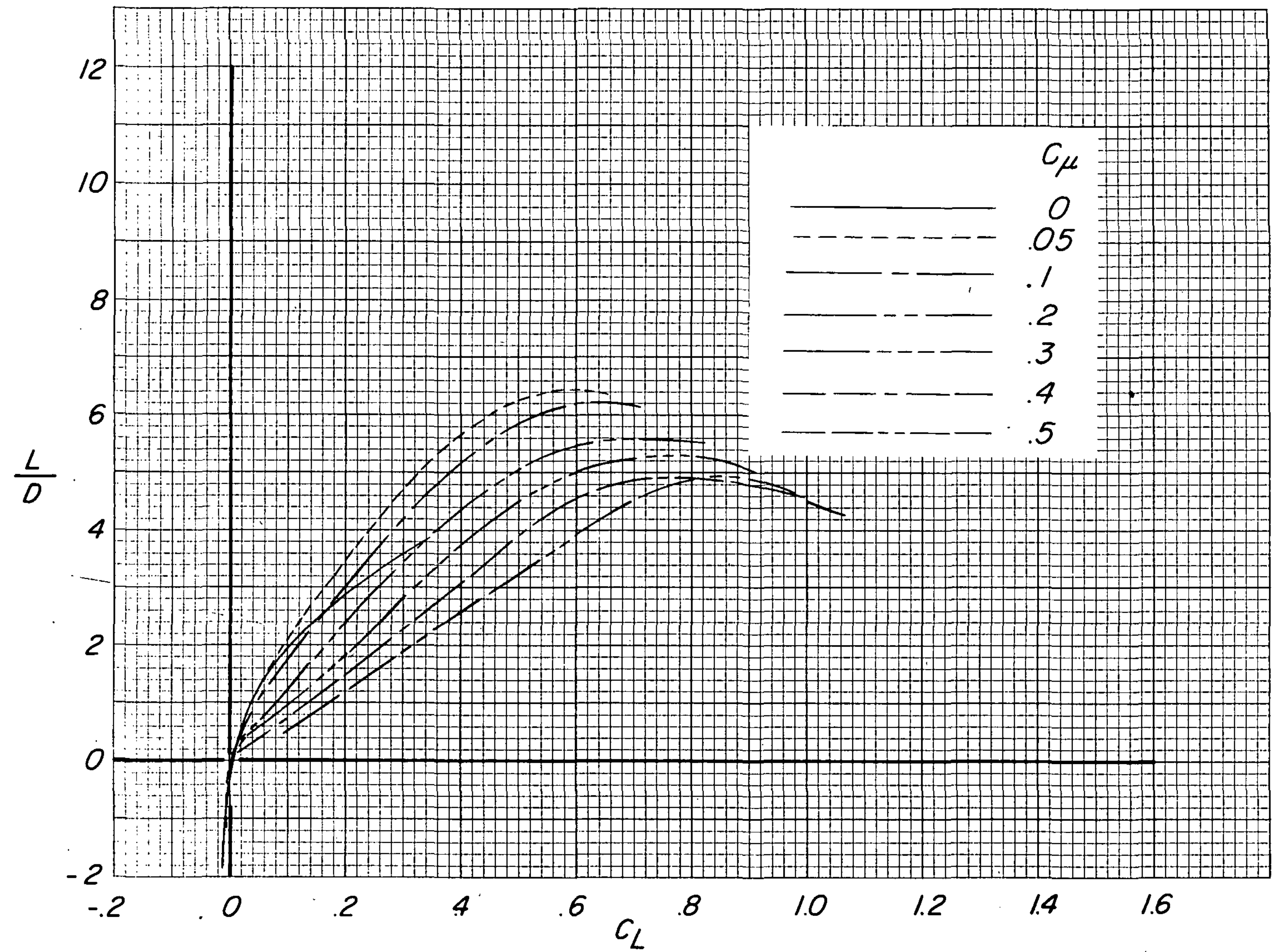
(b) Concluded.

Figure 7.- Concluded.



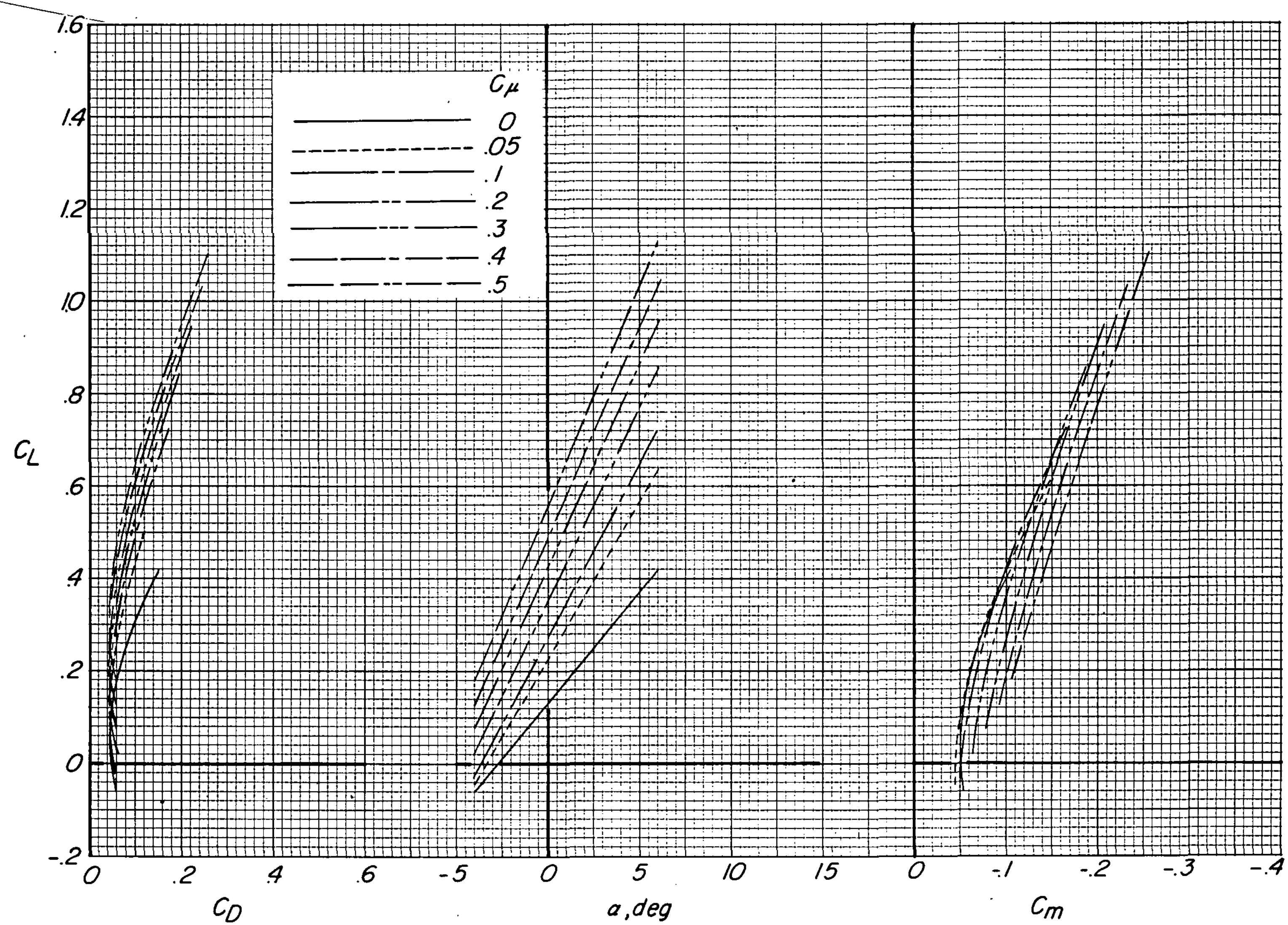
(a) h/b = 0.068.

Figure 8.- Effect of C_μ on the longitudinal aerodynamic characteristics of the model with wing-tip jets deflected 90°.



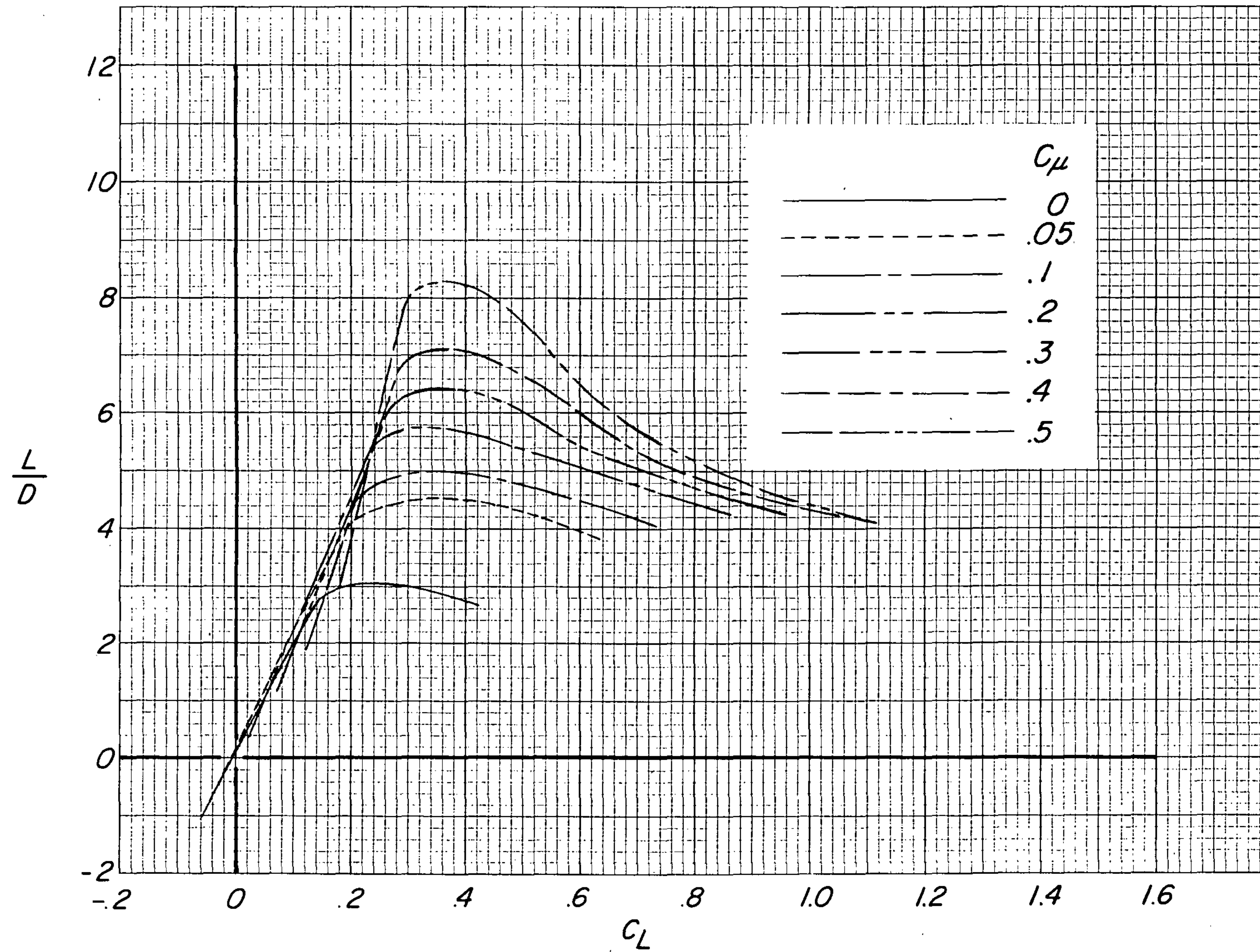
(a) Concluded.

Figure 8.- Continued.



(b) h/b = 0.112.

Figure 8.- Continued.



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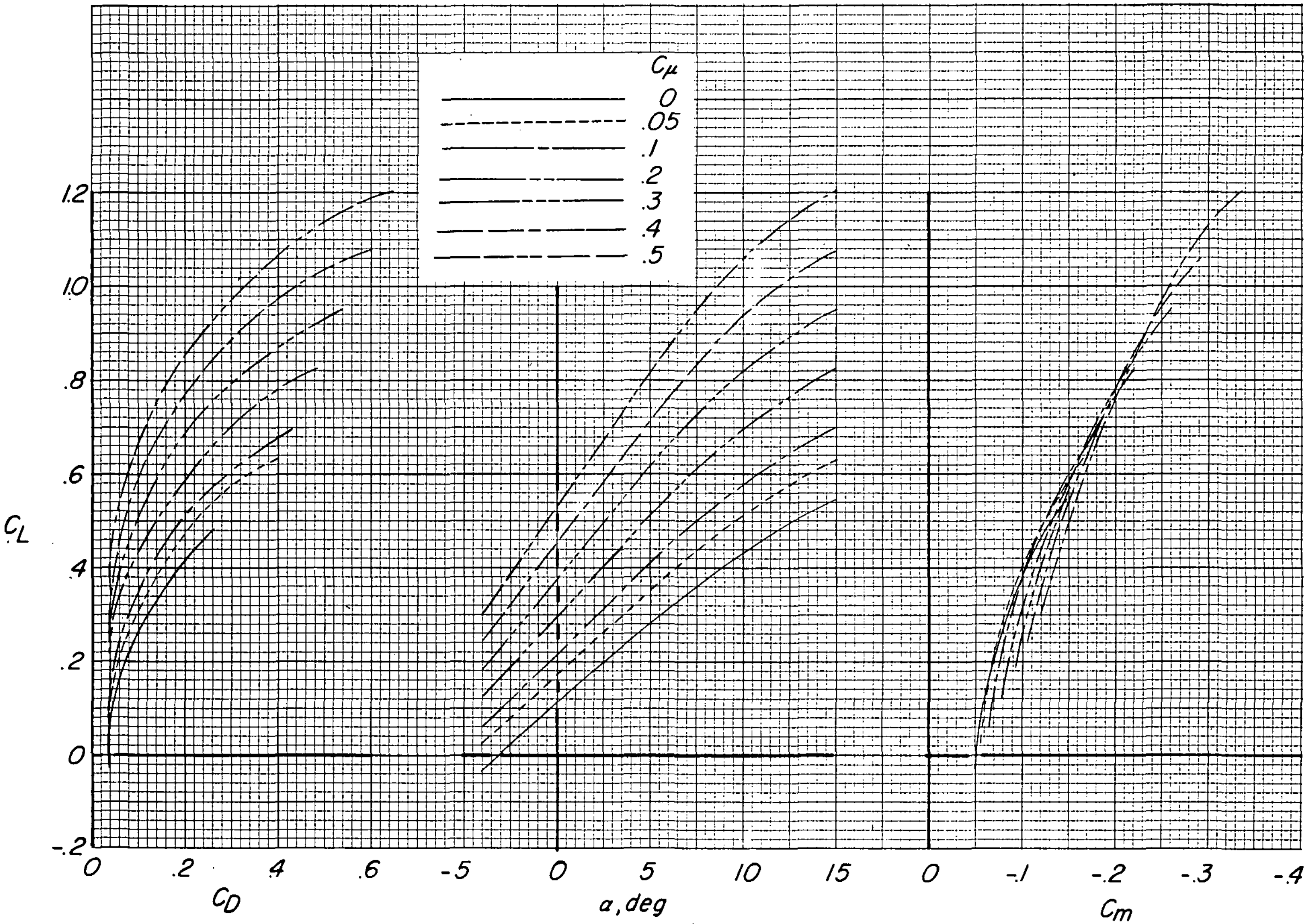
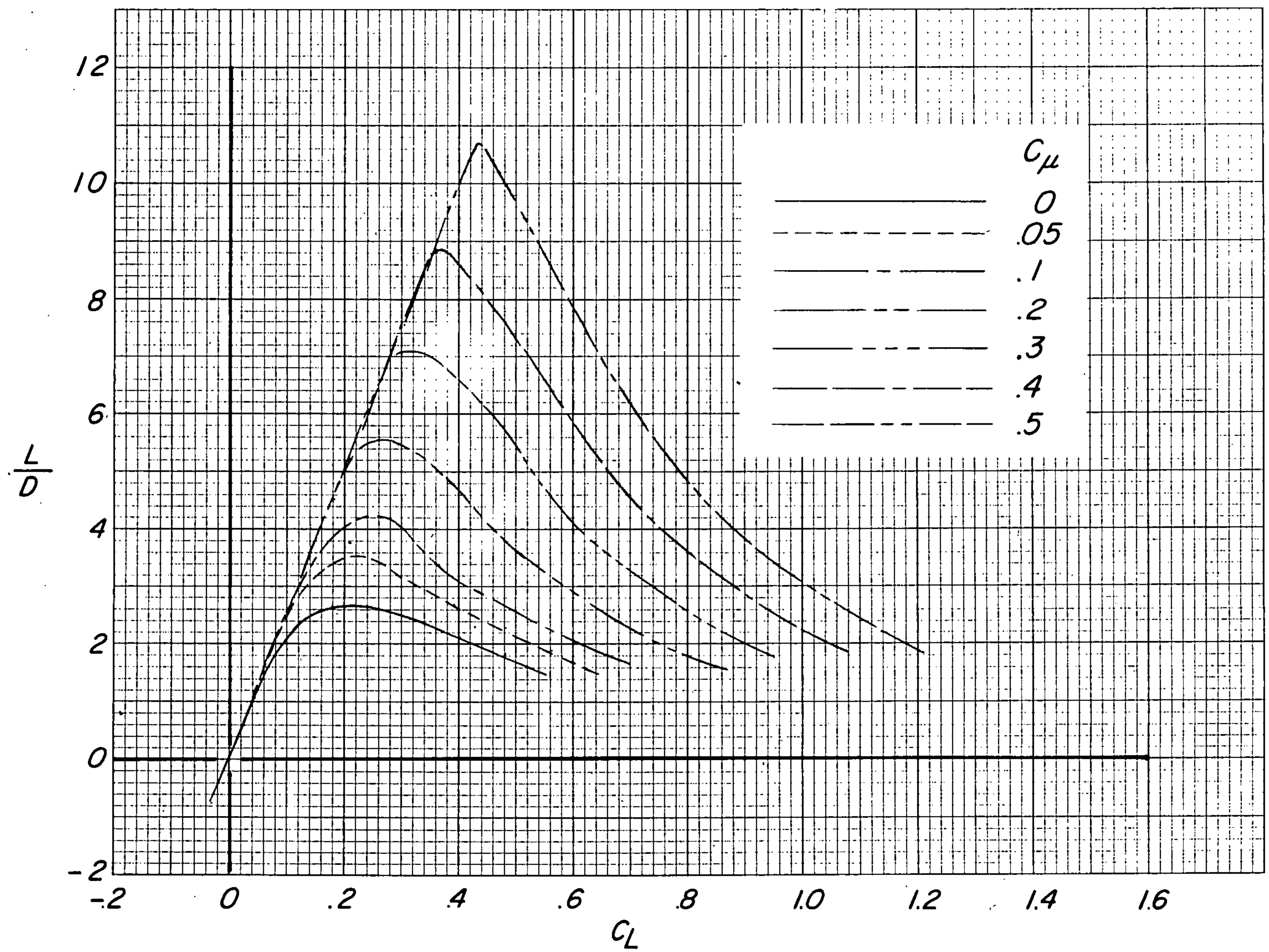


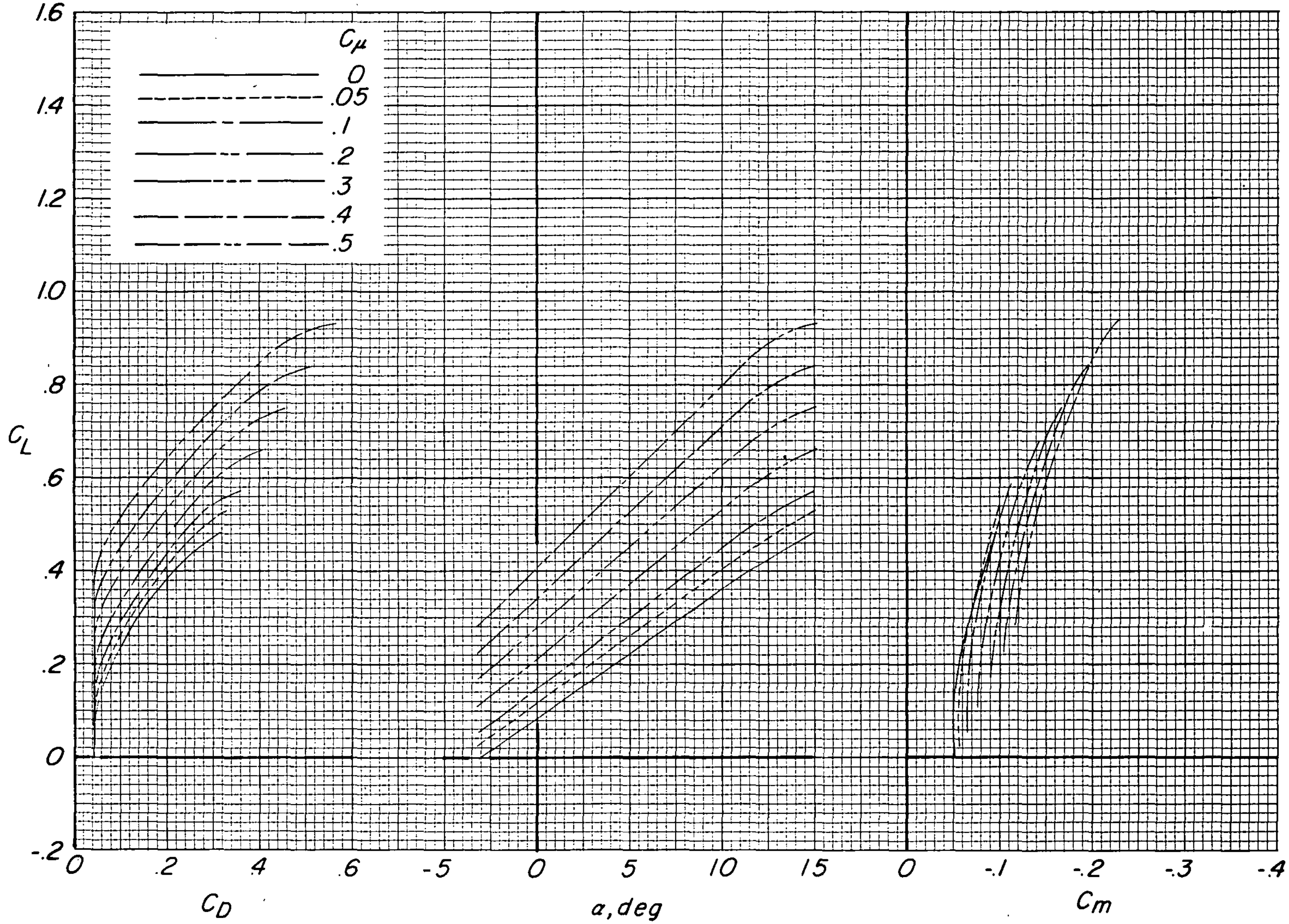
(c) h/b = 0.255.

Figure 8.- Continued.



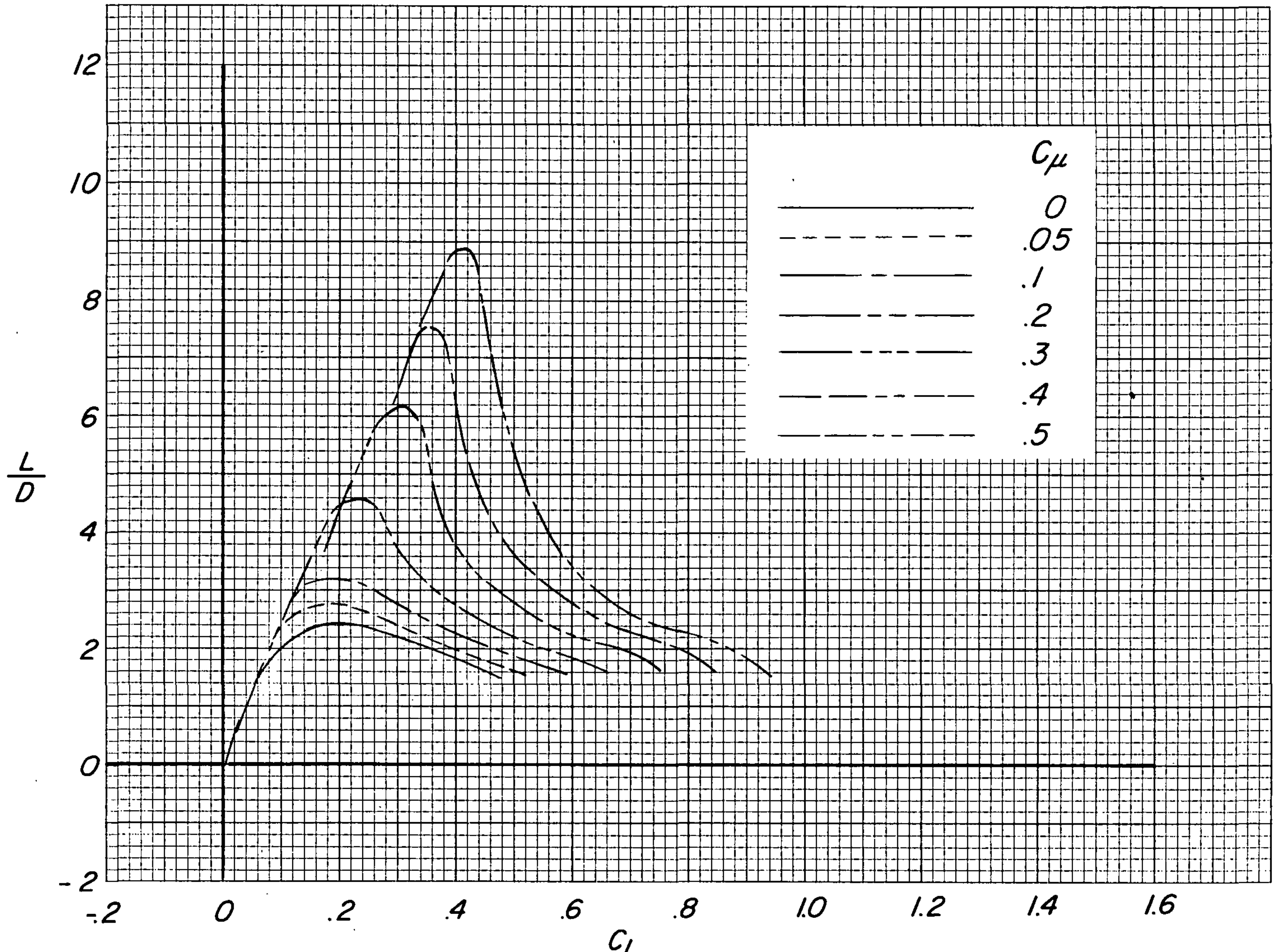
(c) Concluded.

Figure 8.- Continued.



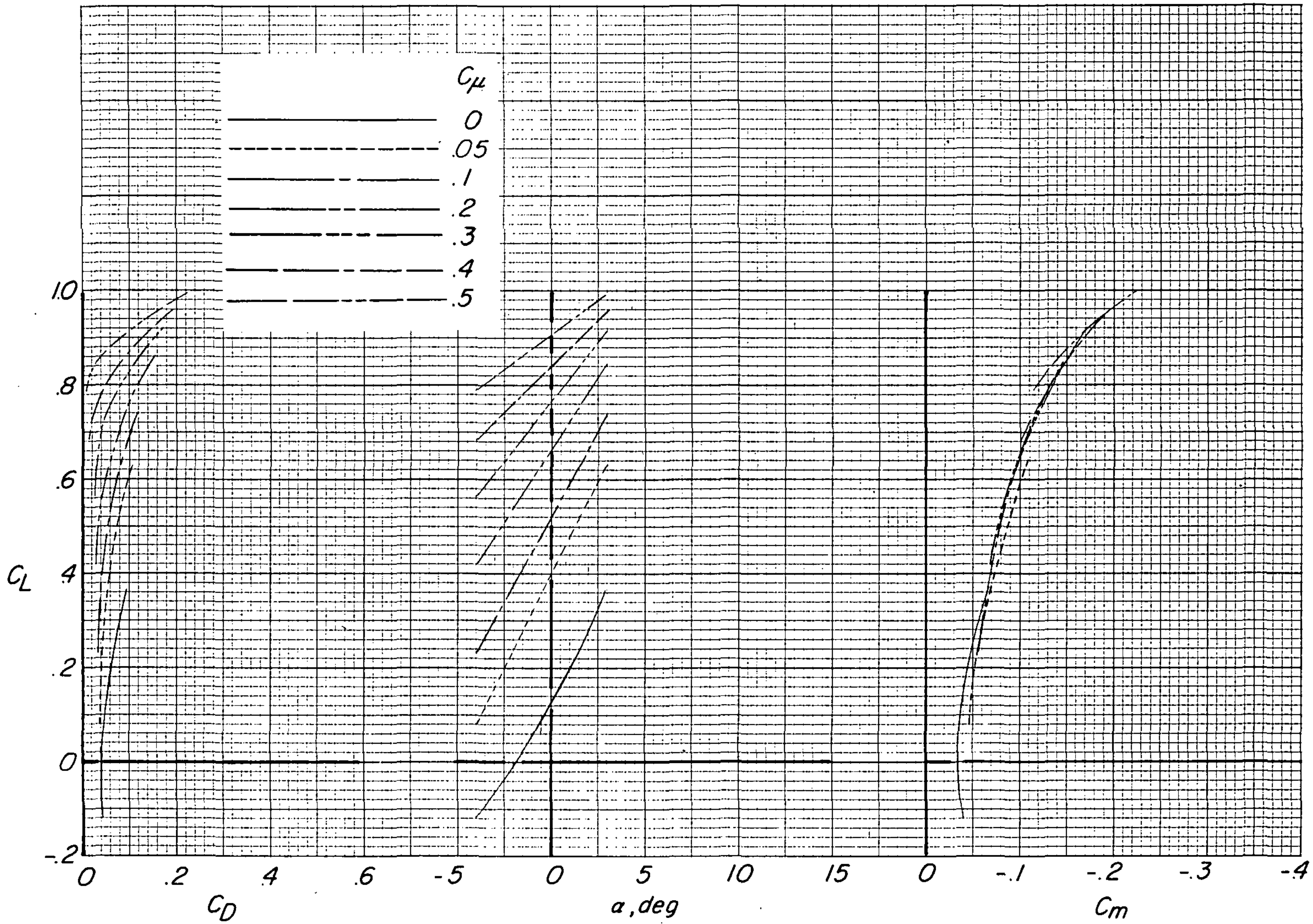
(d) h/b = 1.418.

Figure 8.- Continued.



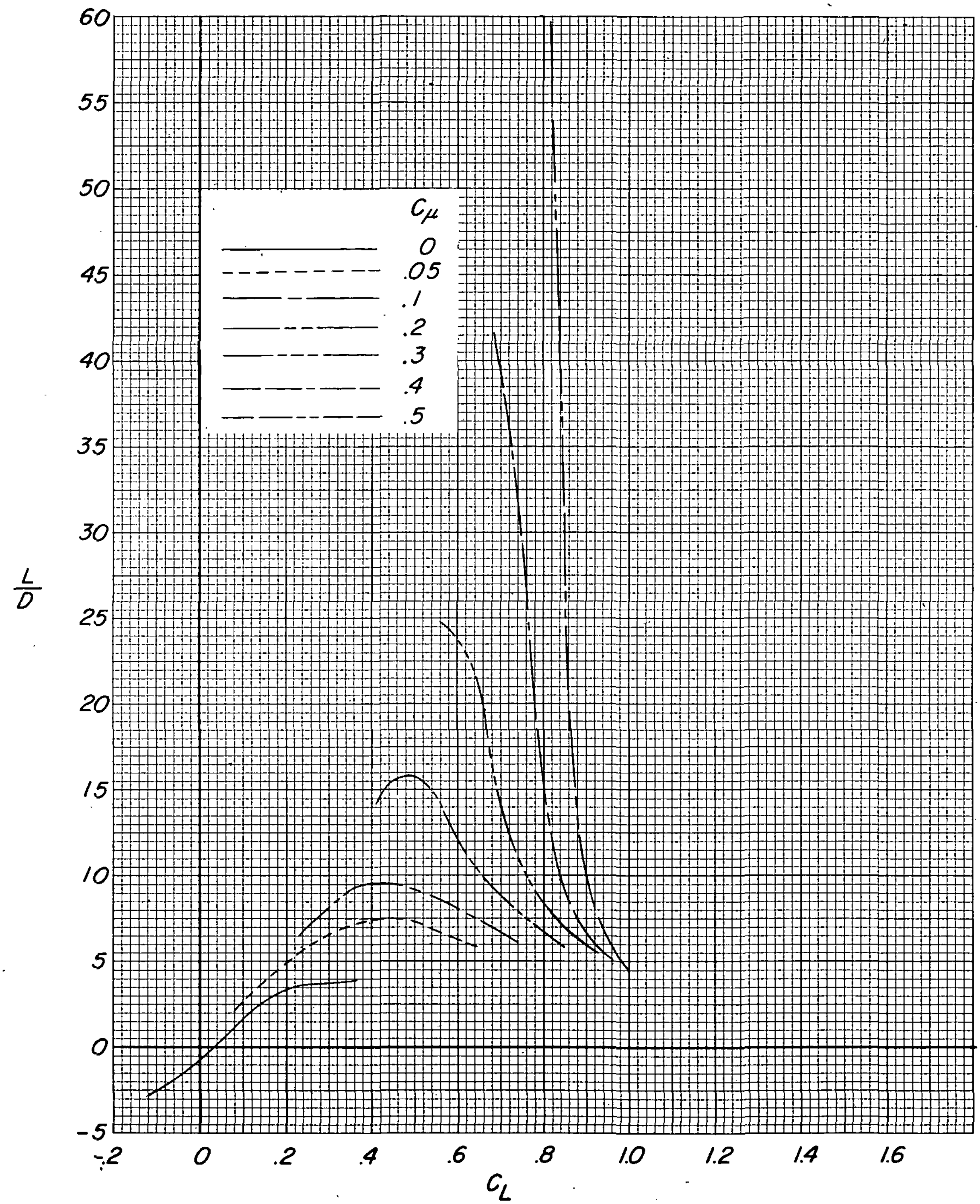
(d) Concluded.

Figure 8.- Concluded.



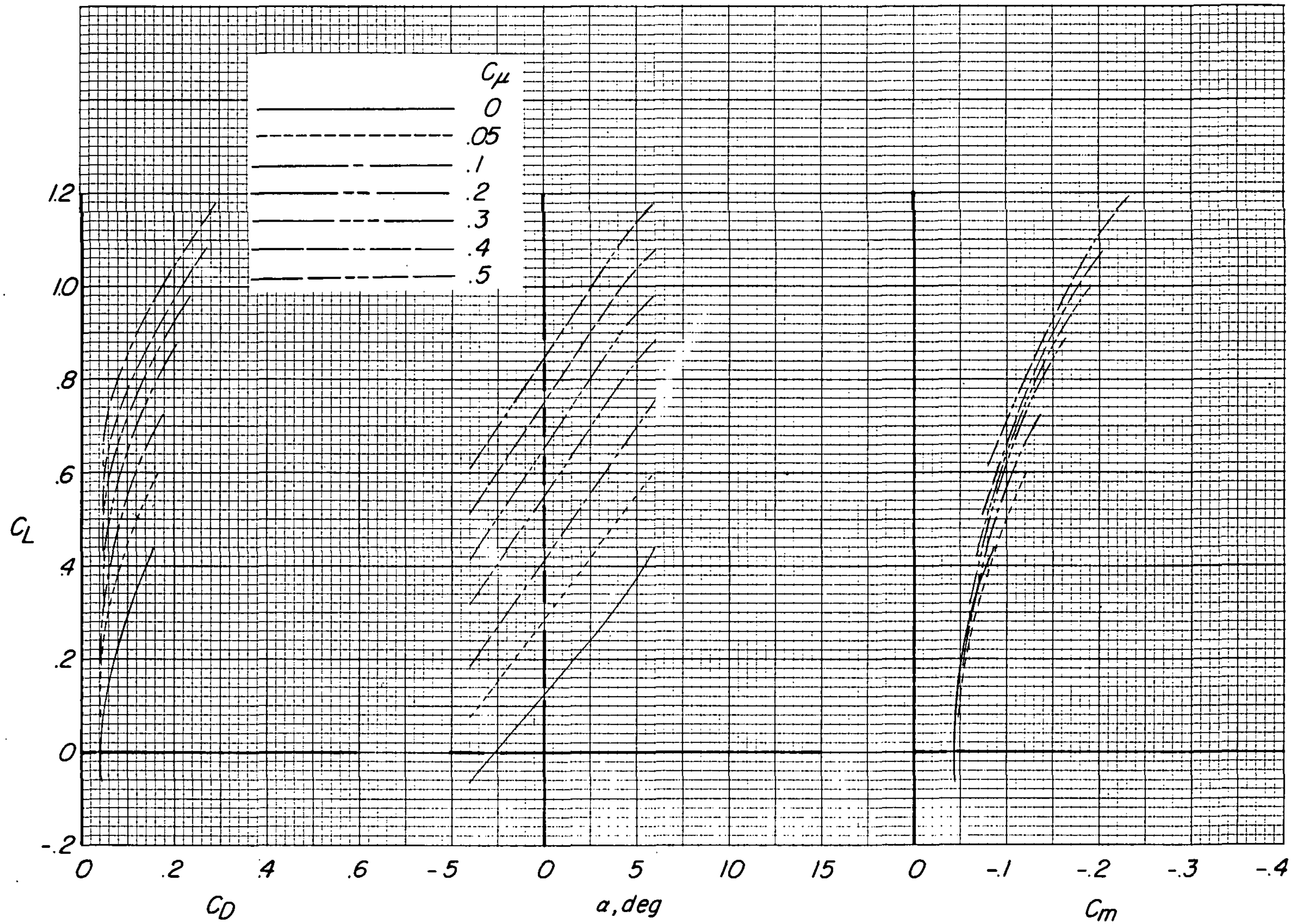
(a) $h/b = 0.063$.

Figure 9.- Effect of C_μ on the longitudinal aerodynamic characteristics of the model with wing-tip jets deflected 135°.



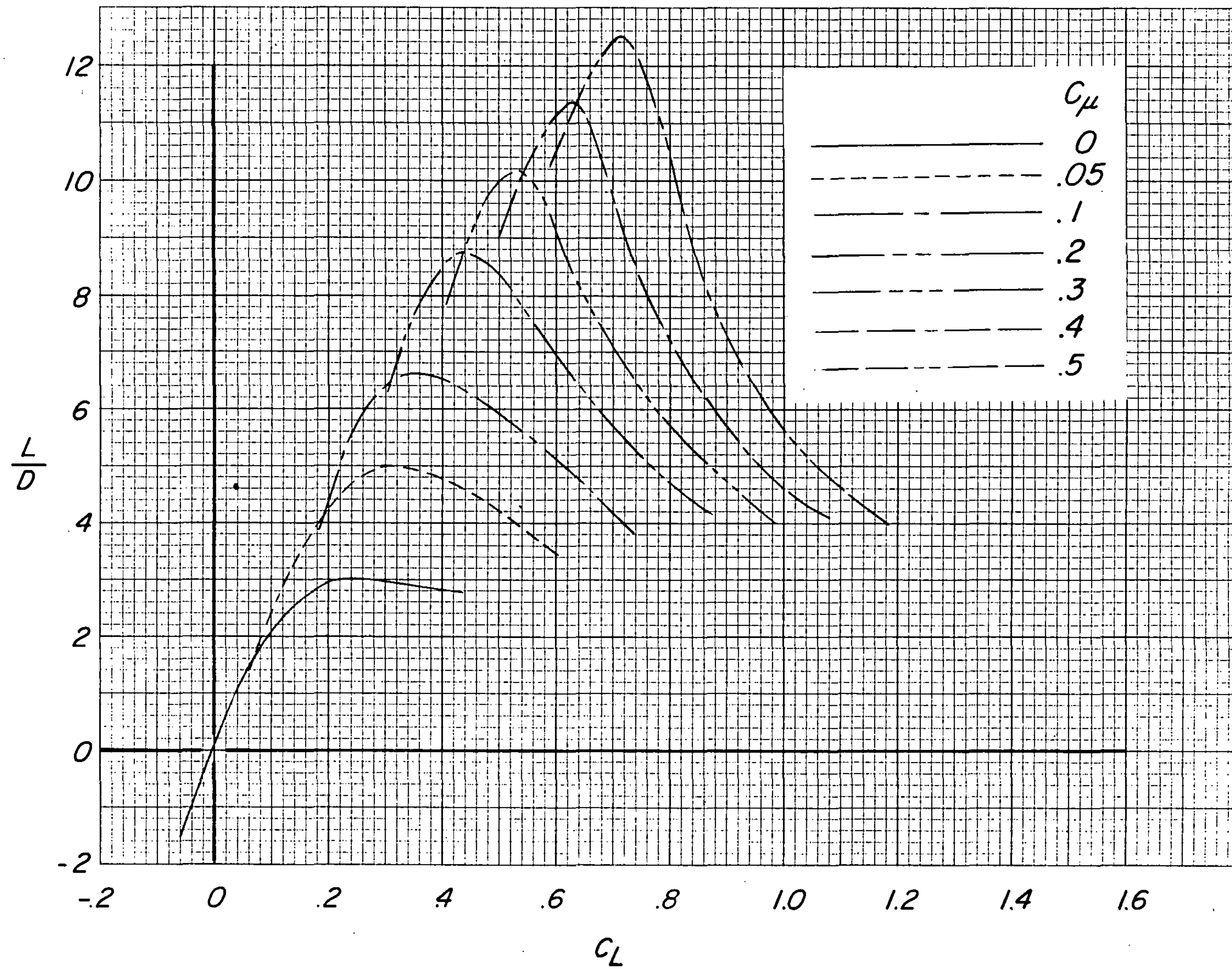
(a) Concluded.

Figure 9.- Continued.



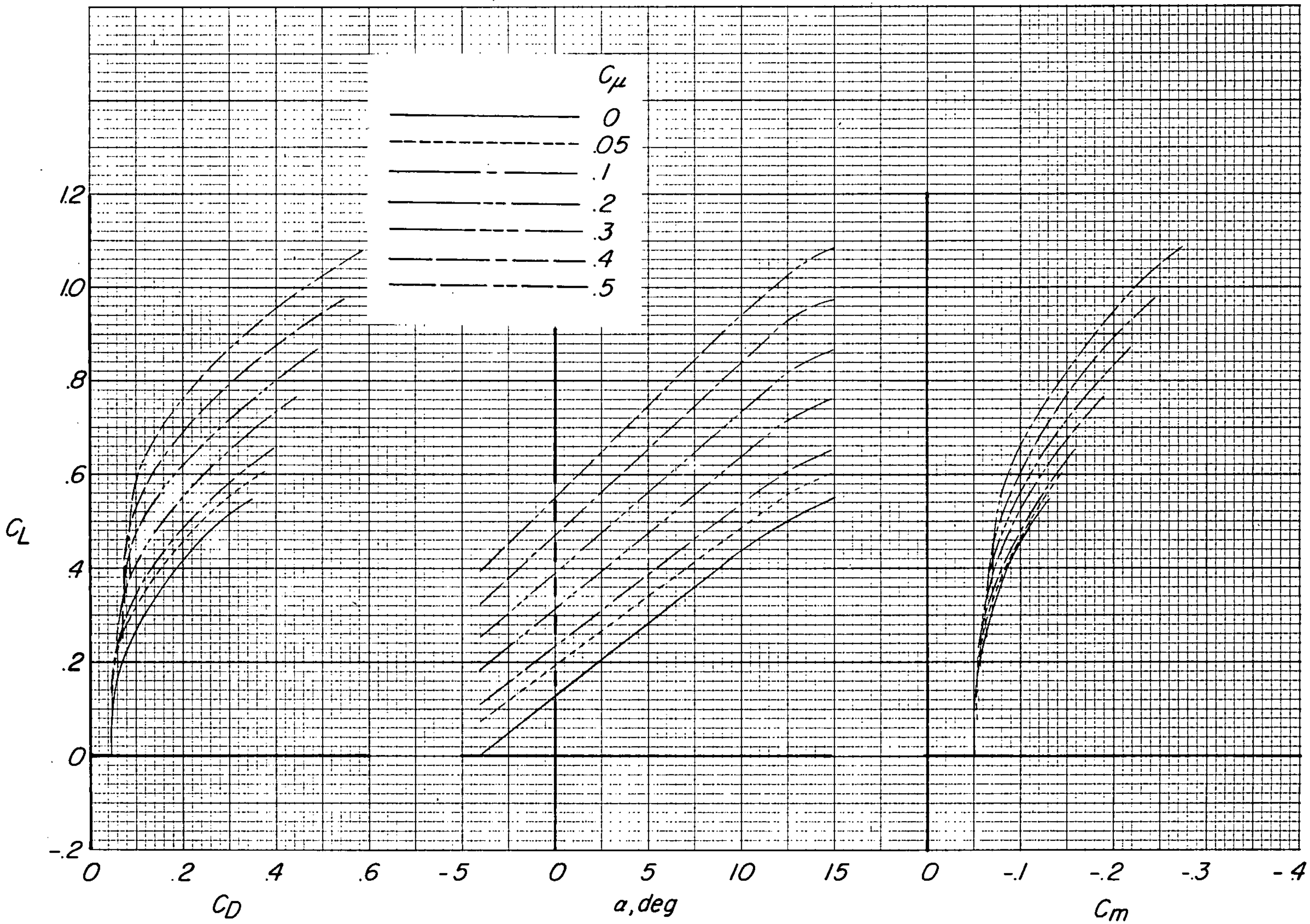
(b) h/b = 0.113.

Figure 9.- Continued.



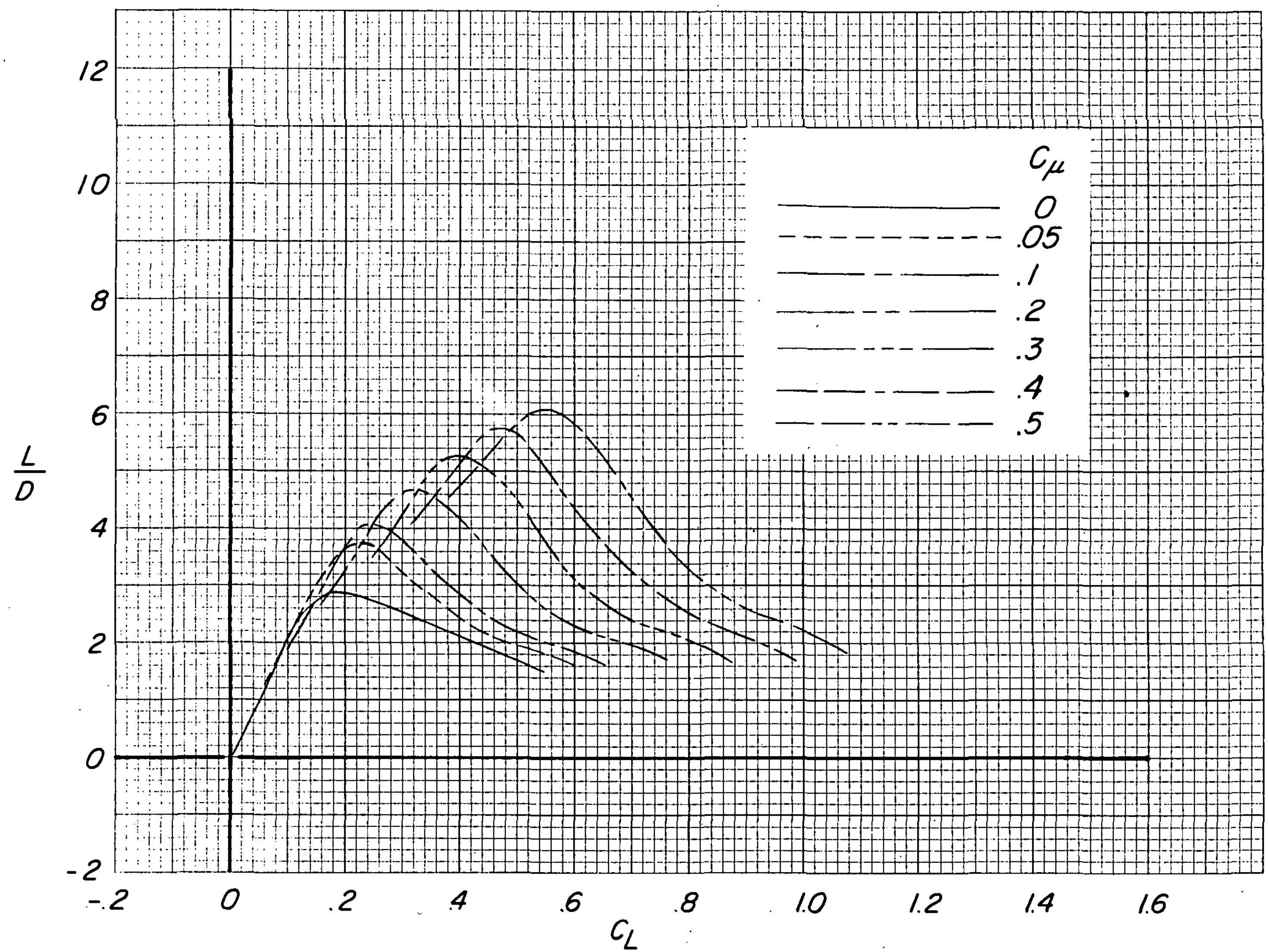
(b) Concluded.

Figure 9.- Continued.



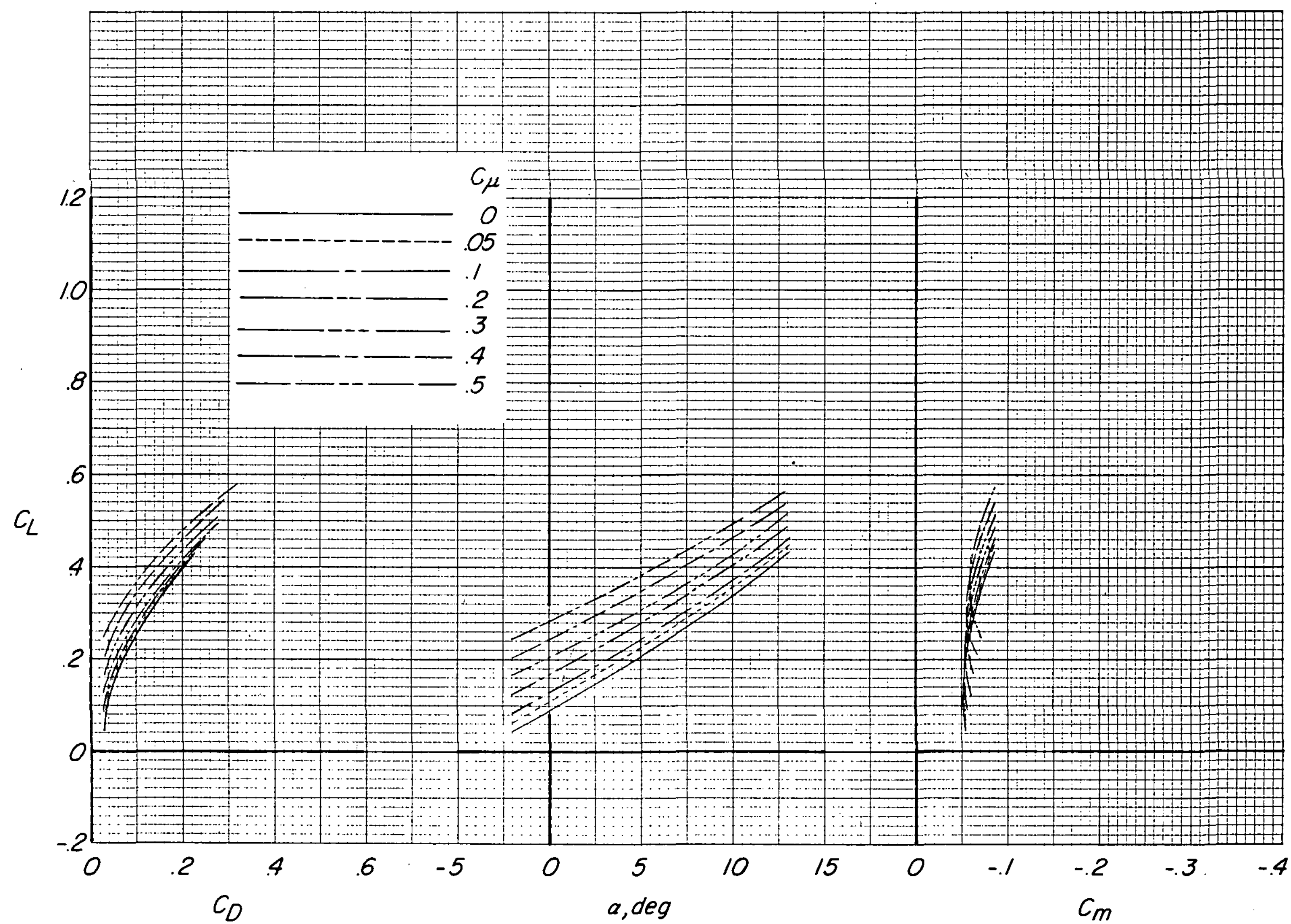
(c) h/b = 0.270.

Figure 9.- Continued.



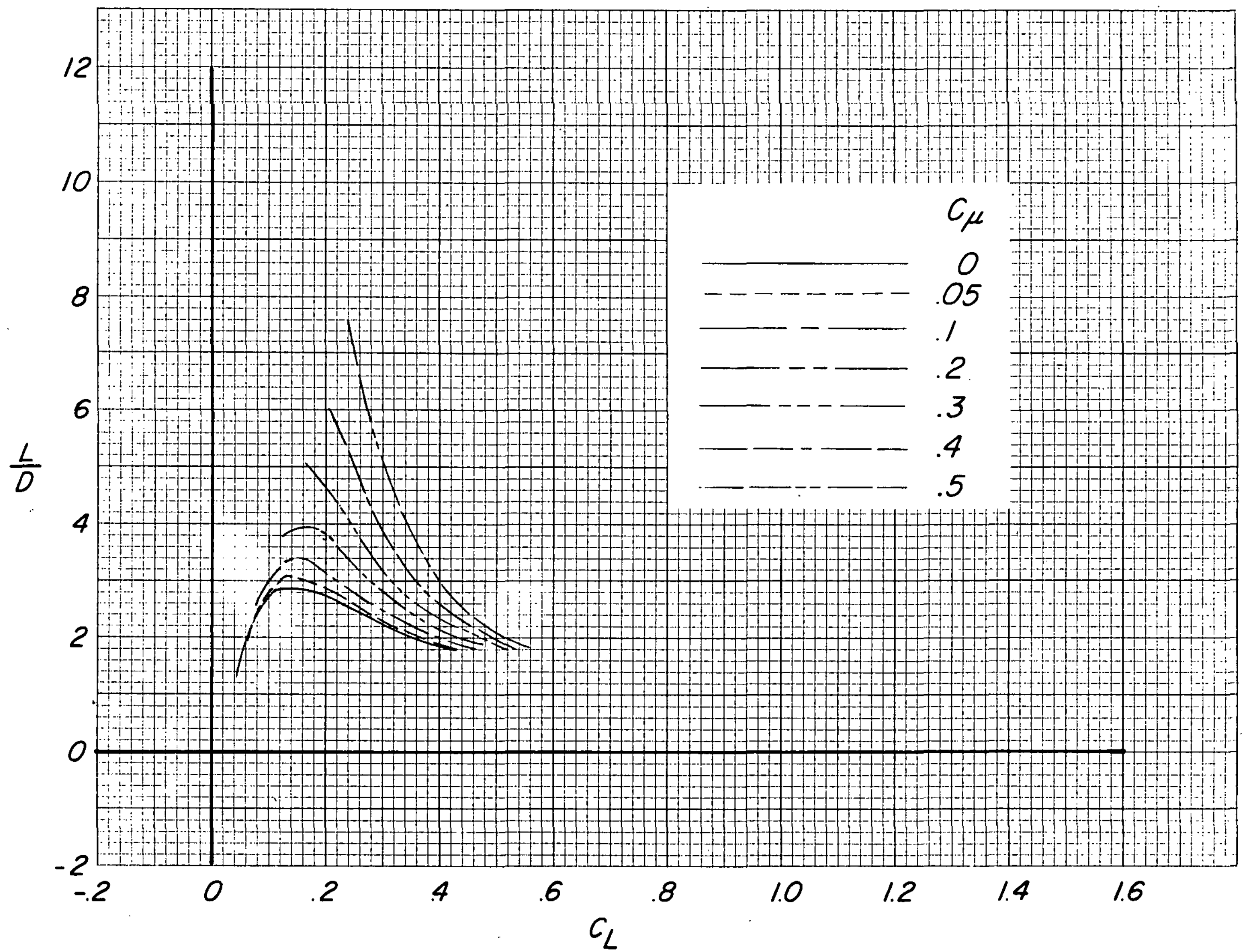
(c) Concluded.

Figure 9.- Continued.



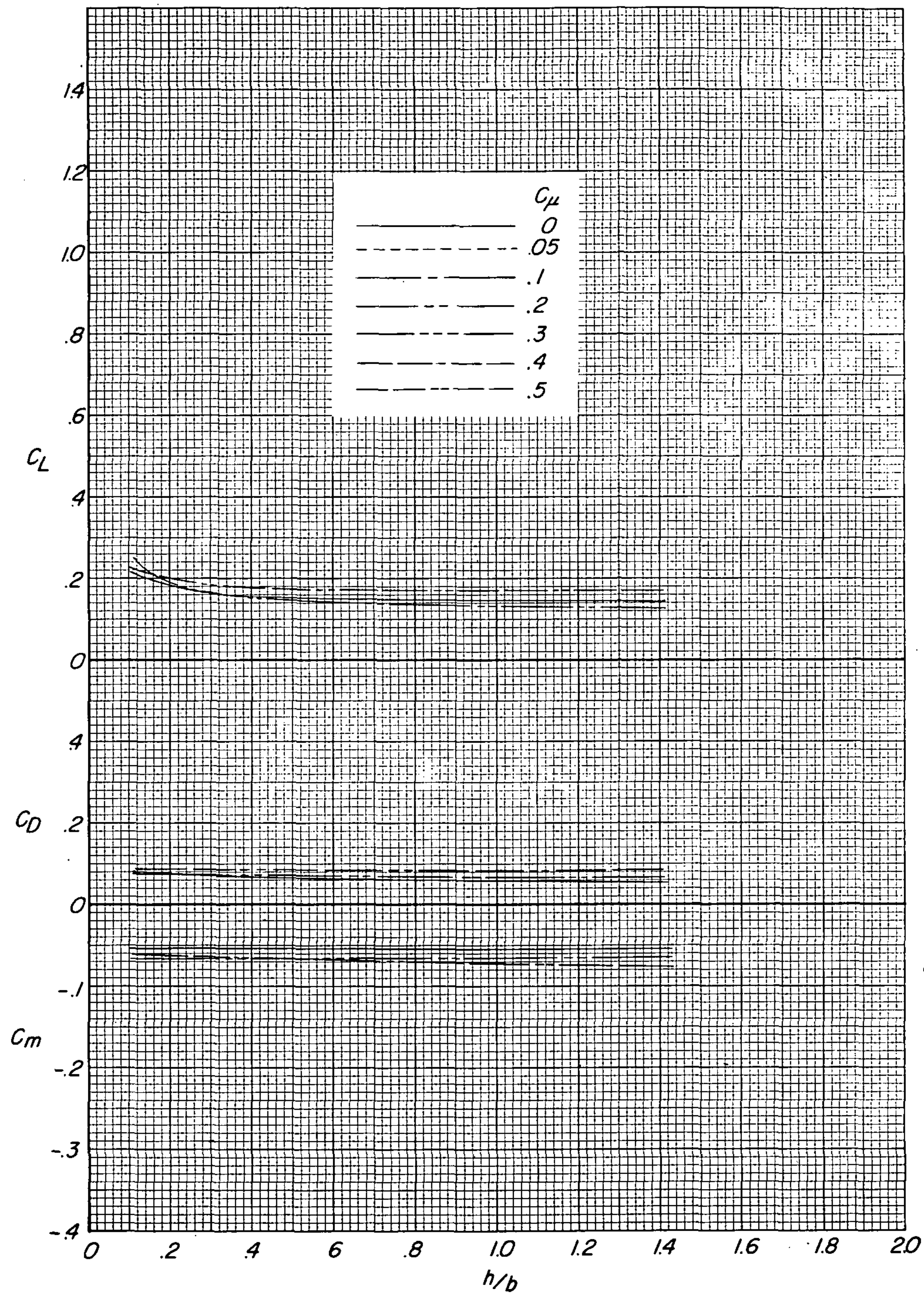
(d) h/b = 1.630.

Figure 9.- Continued.



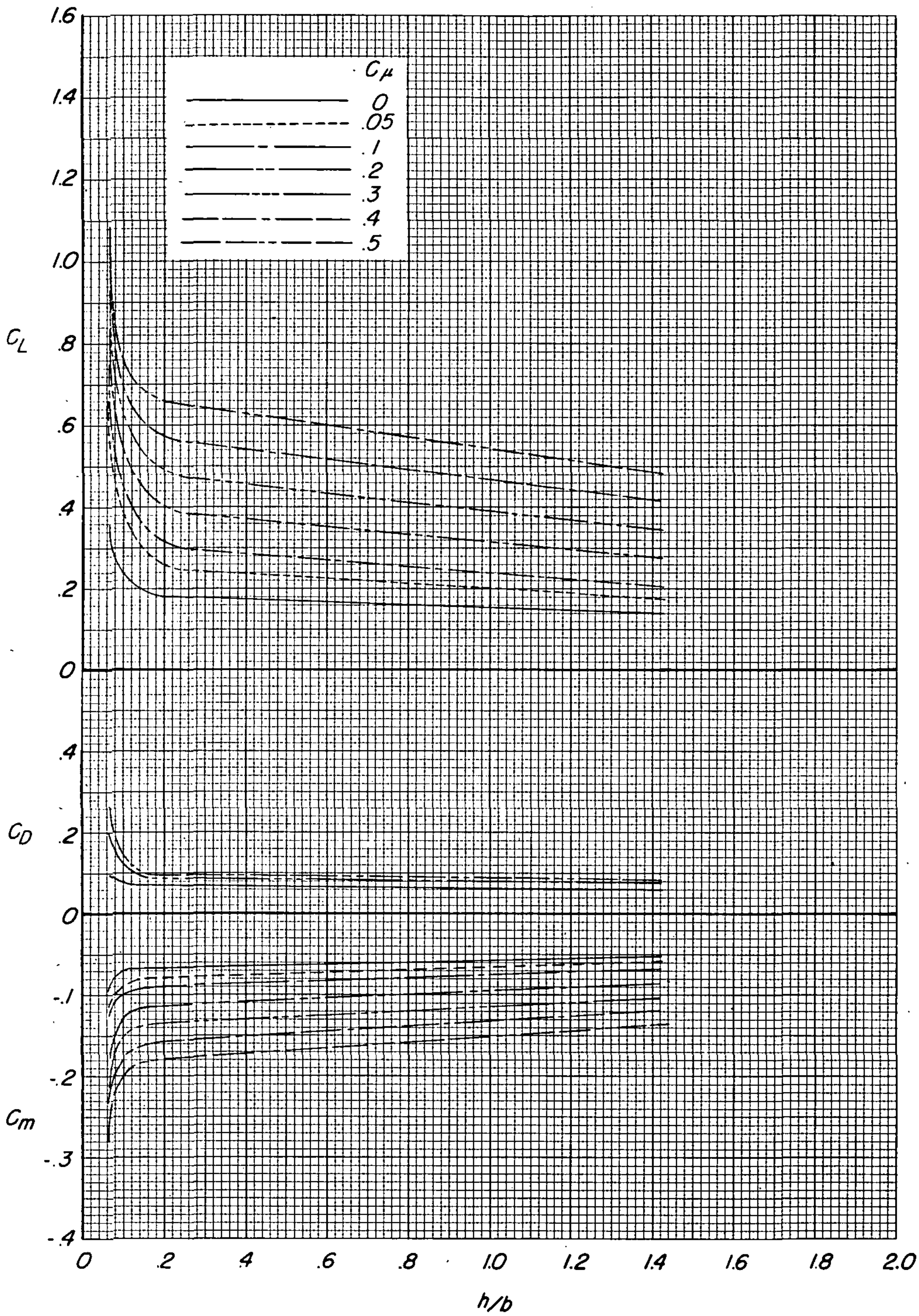
(d) Concluded.

Figure 9.- Concluded.



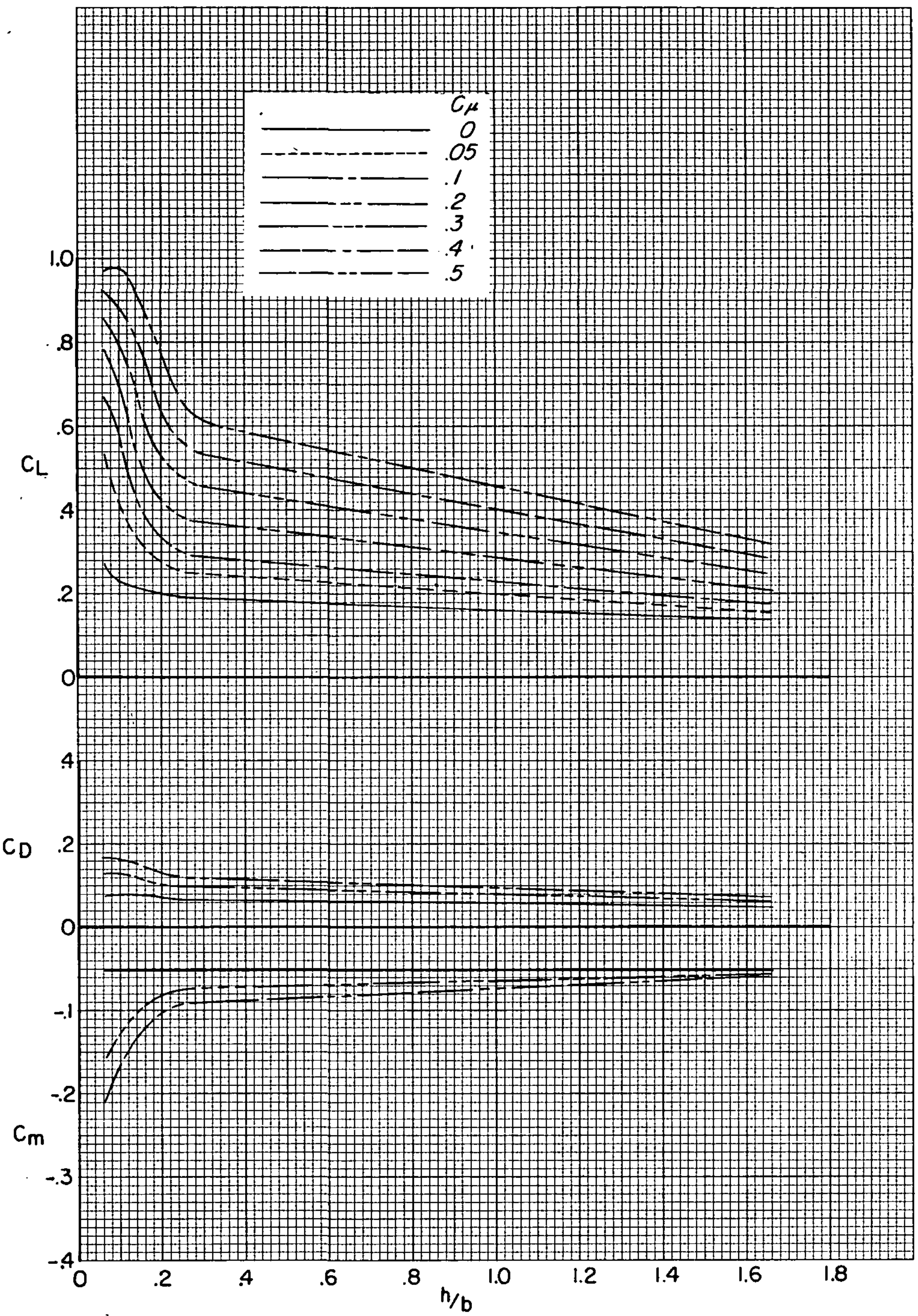
(a) $\delta_j = 0^{\circ}$.

Figure 10.- Variation of the longitudinal aerodynamic characteristics of the model with ground proximity at an angle of attack of 2°.



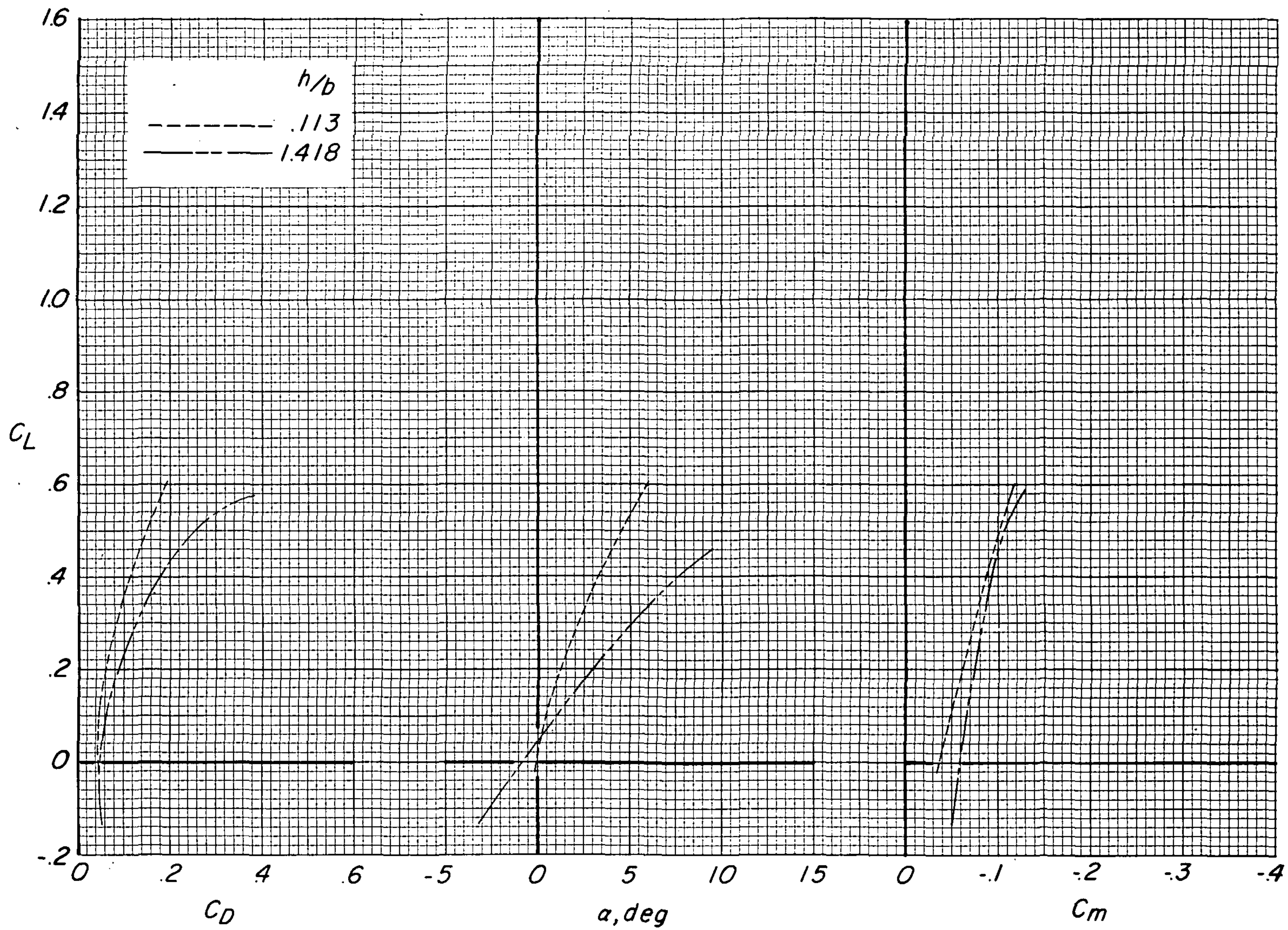
(b) $\delta_j = 90^{\circ}$.

Figure 10.- Continued.



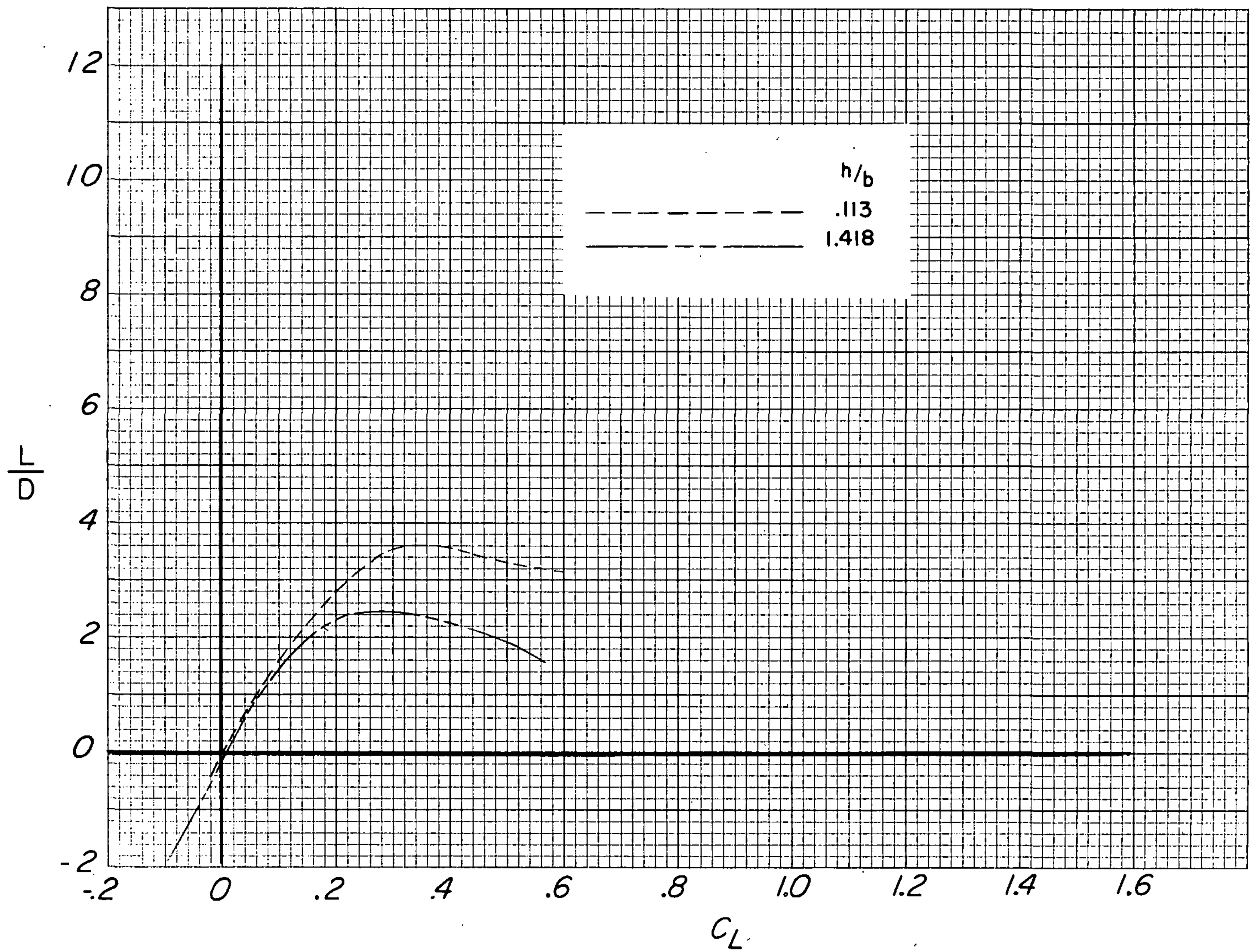
(c) $\delta_j = 135^{\circ}$.

Figure 10.- Concluded.



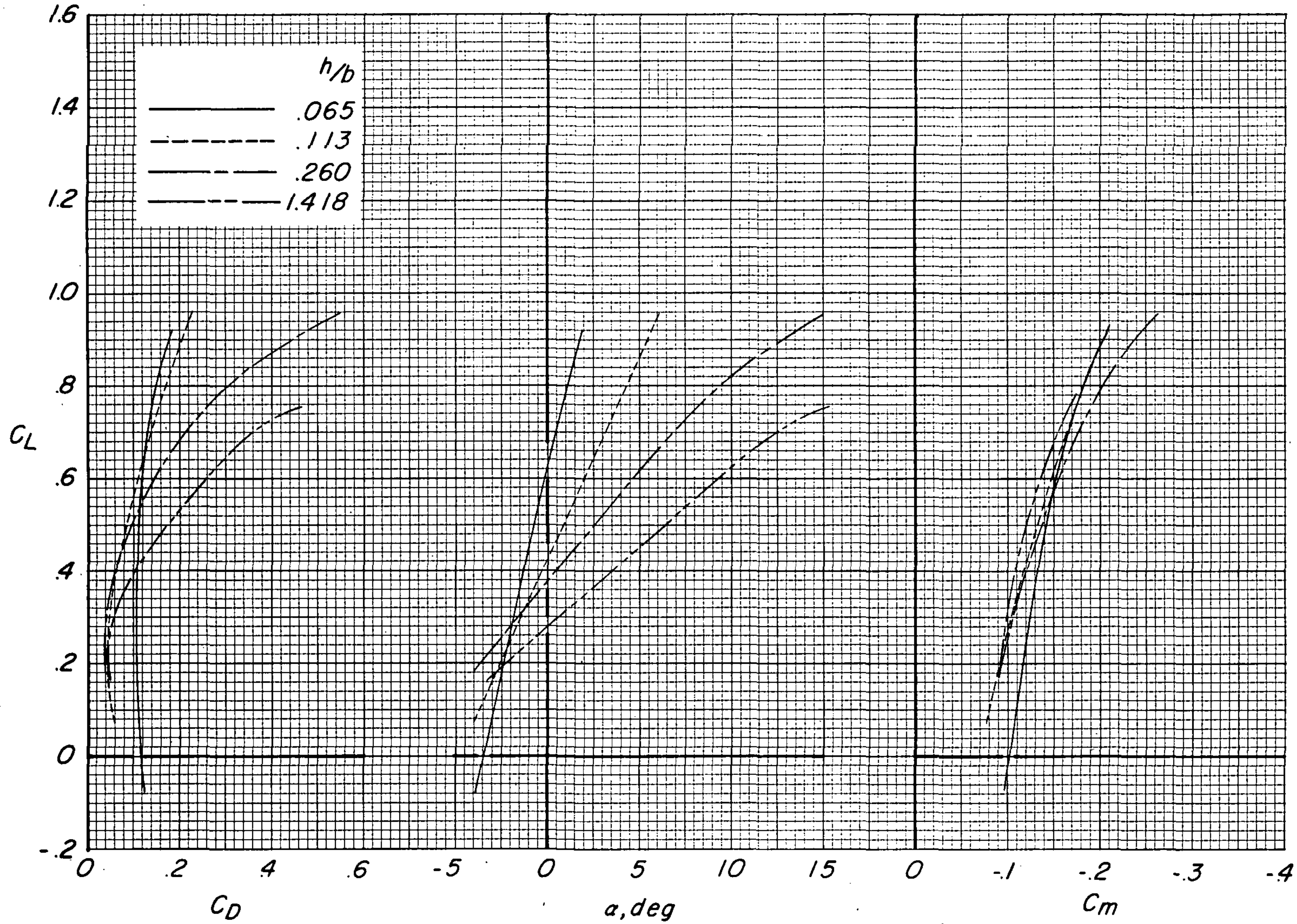
(a) $\delta_j = 0^{\circ}$.

Figure 11.- Effect of ground proximity on the longitudinal aerodynamic characteristics of the model at a C_{μ} of 0.3.



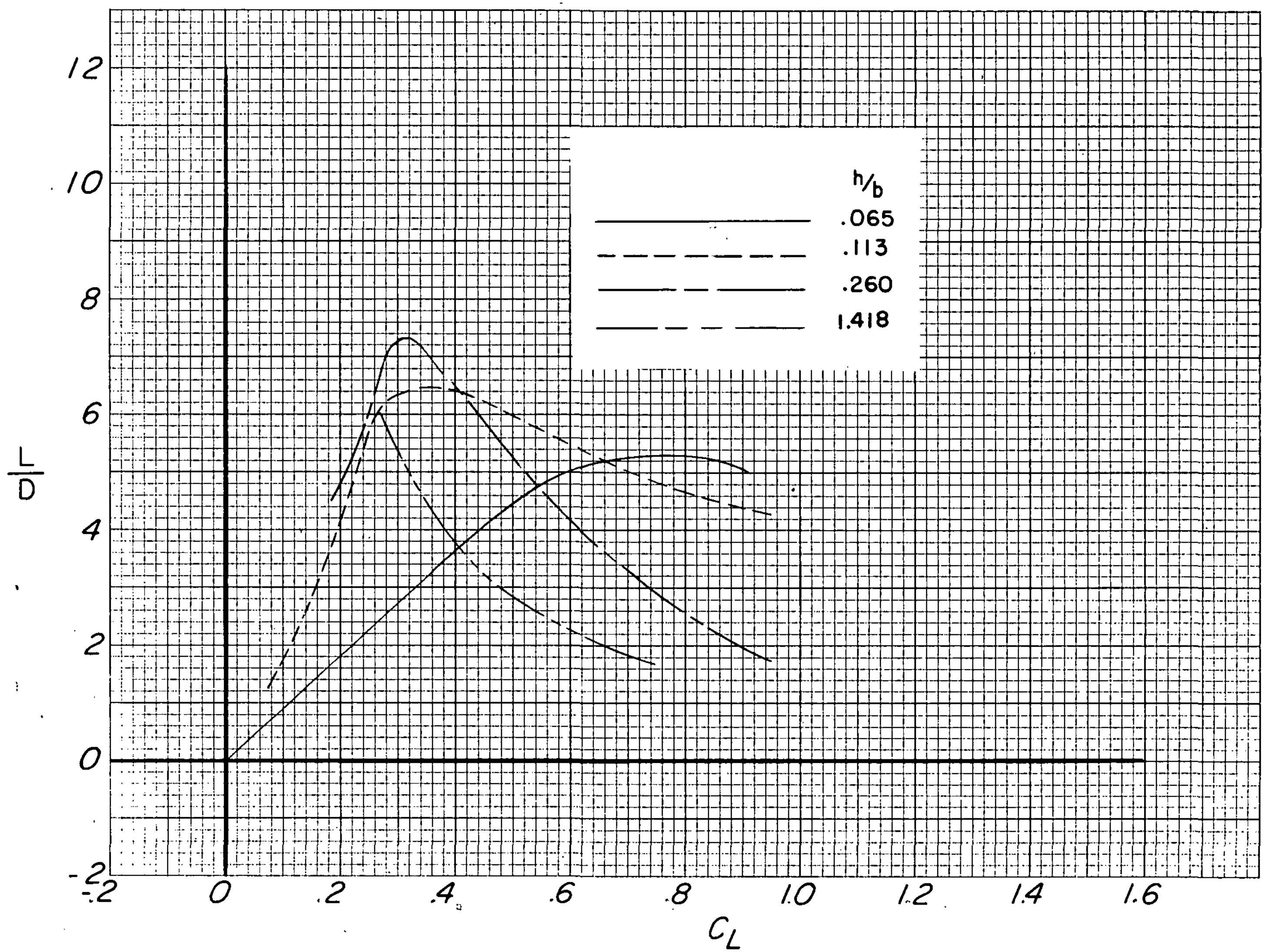
(a) Concluded.

Figure 11.- Continued.



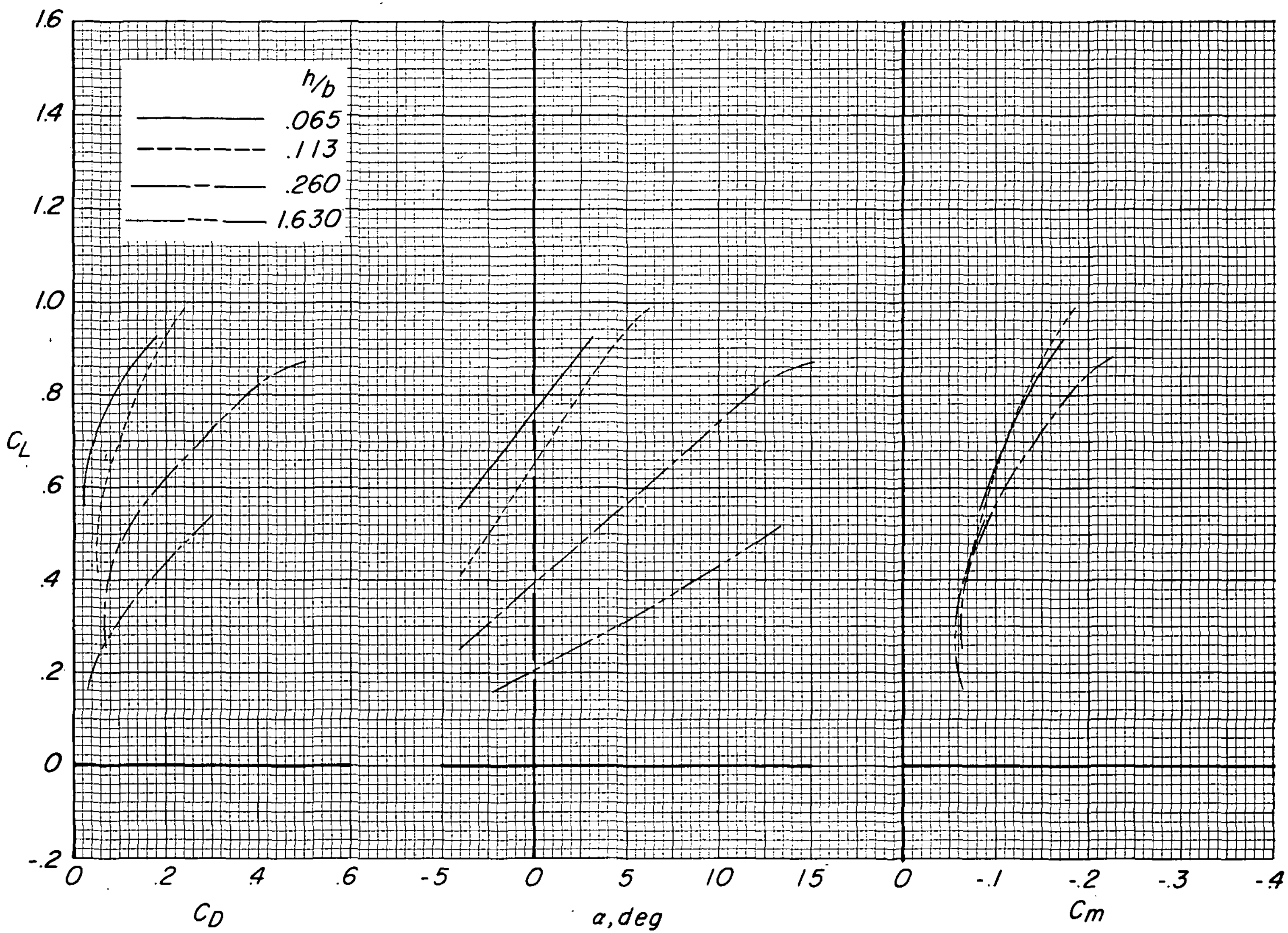
(b) $\delta_j = 90^{\circ}$.

Figure 11.- Continued.



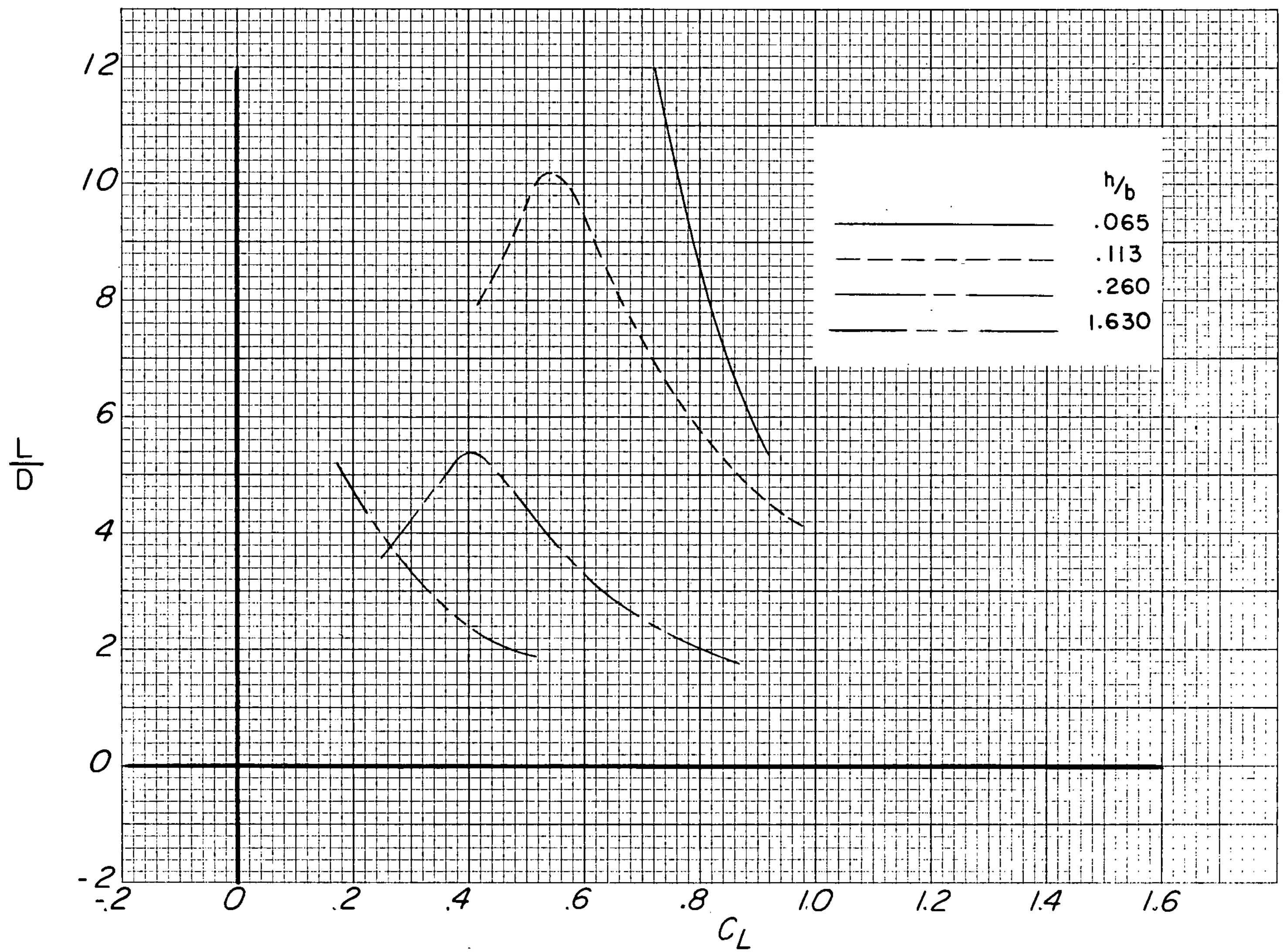
(b) Concluded.

Figure 11.- Continued.



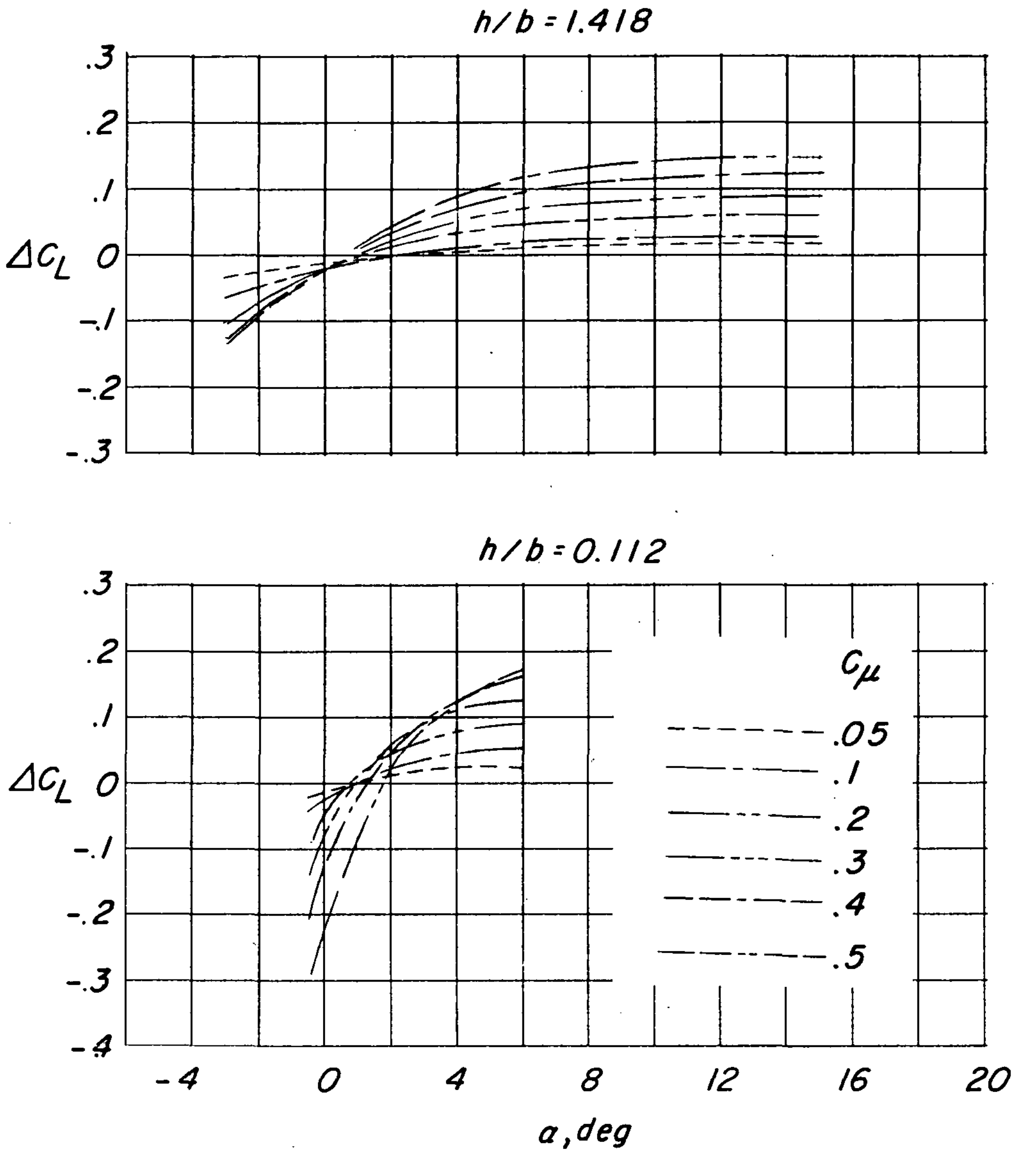
(c) $\delta_j = 135^{\circ}$.

Figure 11.- Continued.



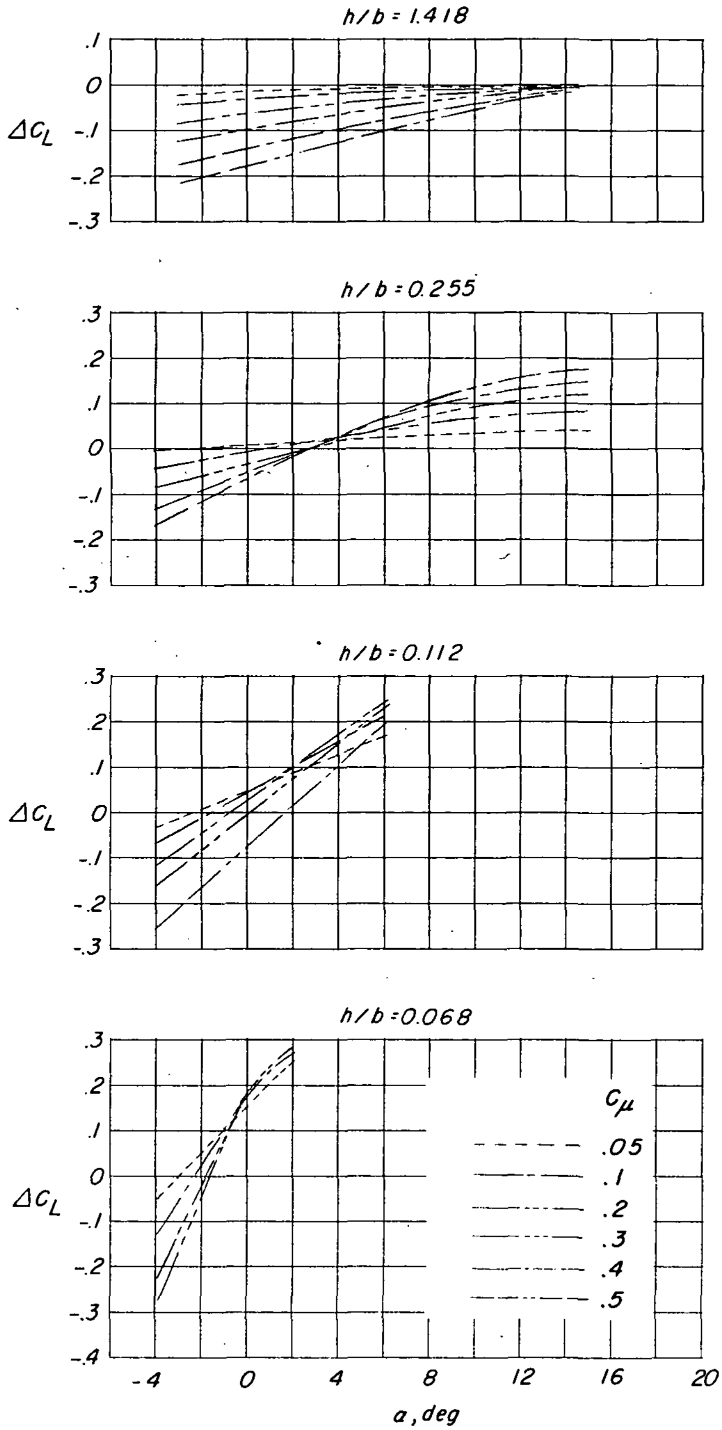
(c) Concluded.

Figure 11.- Concluded.



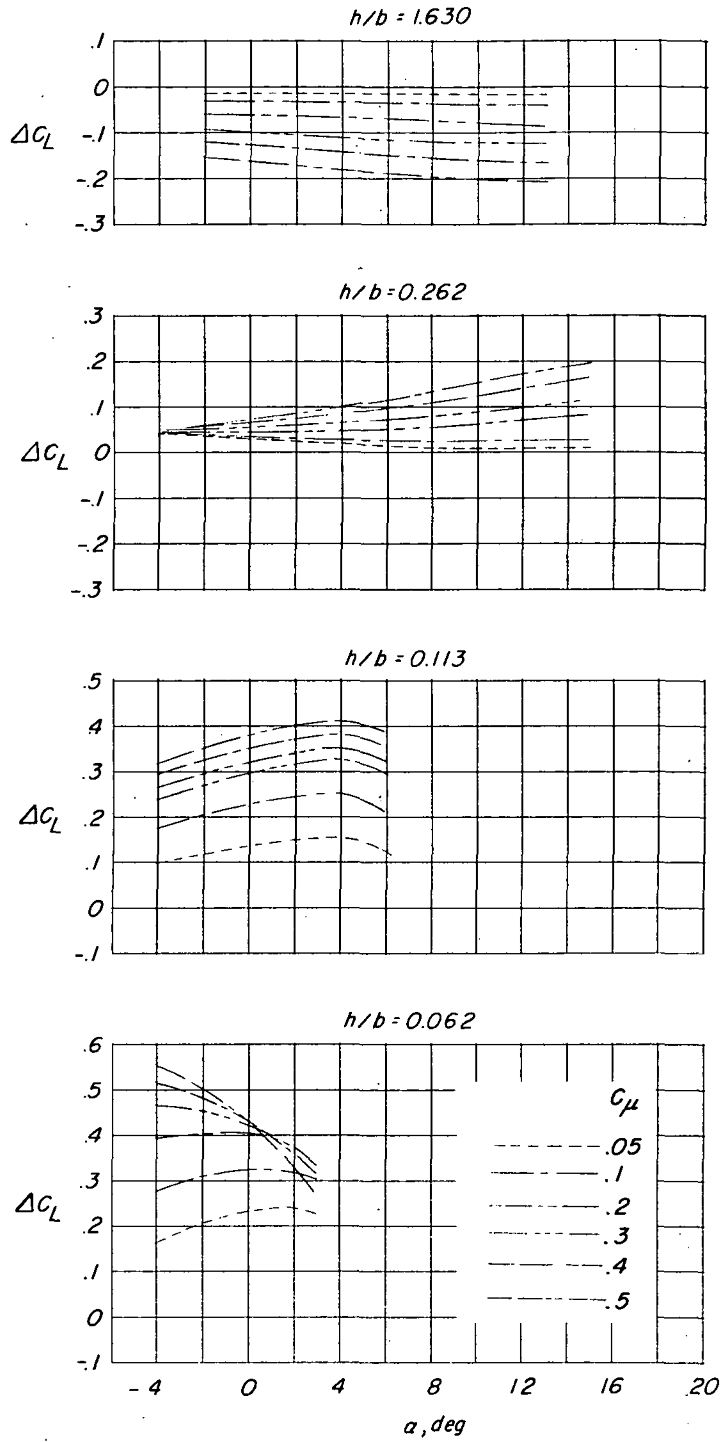
(a) $\delta_j = 0^o$.

Figure 12.- Effect of tip jet blowing coefficient on the interference of the tip jet flow on the airfoil lift.



(b) $\delta_j = 90^{\circ}$.

Figure 12.- Continued.



(c) $\delta_j = 135^\circ$.

Figure 12.- Concluded.

NASA-Langley, 1974 L-9539

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—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

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